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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

GODDARD SPACE FLIGHT CENTER

1972 GSFC BATTERY WORKSHOP

SECOND DAY

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

GODDARD SPACE FLIGHT CENTER

1972 GSFC BATTERY WORKSHOP

SECOND DAY

Building 7-Room 231
Goddard Space Flight Center
Greenbelt, Maryland

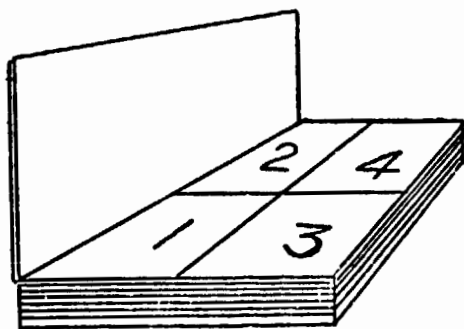
Wednesday, 15 November 1972

Gerald Halpert
Workshop Chairman

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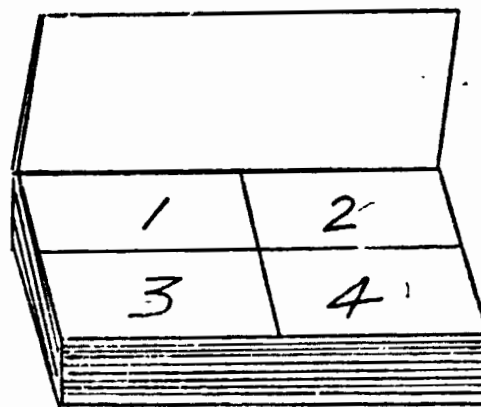
NOTE

IN GENERAL THERE ARE FOUR SLIDES PER PAGE. THE SLIDE SEQUENCE IS THE FOLLOWING, REGARDLESS OF BOOK ORIENTATION.



(Vertical)

FIGURE NO. 1



(Horizontal)

FIGURE NO. 2

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Results of the Surveys:

I. Specification.

The results on the survey on use and experience with the latest interim model specification S-761-P-6 appears below. It is somewhat disappointing to note that only 50 of the 120 attendees took part. GSFC personnel were not included in the survey. Of the 50, nine were manufacturers.

The consensus of opinion is that the majority of the spec is used but improvement and updating is necessary. The areas range from additional acceptance tests for materials to additional performance tests. However, some feel that the spec is too inclusive and others desire additional requirements. It depends on whether the individual is a manufacturer, user or in R&D. The comments from section 5 of the questionnaire are listed for your interest.

SPECIFICATION

Since 1968, considerable progress has been made towards the development of a viable specification for aerospace nickel - cadmium cells. Starting with the Interim Model Specification developed by NASA/Industry users, an evolution of this specification has developed. GSFC is currently revising specification S-761-P-6. We invite your comments and appreciate your answers to the following questions related to this specification.

1. Please check the appropriate space(s)
 - A. 9 manufacturer
 - B. 17 user
 - 5 aerospace (NASA)
 - 10 aerospace/military (DOD)
 - 6 commercial/industry
 - C. 3 none of the above(explain) 1) NASA Dev.
2) R&D, 3) R&D
2. Have you used the GSFC specification in the procurement of nickel - cadmium cells?
 - A. 2 in total
 - B. 9 partially (quoted excerpts from spec.)
 - C. 7 referenced (used material in preparing company spec.)
 - D. 7 not used
 - E. 8 other (explain) _____

3. What are your feelings or opinions toward this type of specification?

- A. 2 needed, no changes necessary
- B. 13 needed, requires minor improvement (includes 6 manufacturers)
- C. 9 needed, requires considerable improvement (includes 3 manufacturers)
- D. 1 not needed
- E. 7 other (briefly explain) _____

4. Since the Interim Model Specification was published, a great deal of knowledge has been acquired on the performance of nickel - cadmium cells. Which of the following do you feel should be emphasized in current generation of specifications.

- | | | Includes
manufacturers |
|----|--|---------------------------|
| A. | 13 performance requirements on delivered cells | 5 |
| B. | 5 detail processing requirements | 0 |
| C. | 12 combination of above | 3 |
| D. | 6 other (briefly explain) _____ | 1 |

5. Please list by subject and category those areas pertaining to the nickel - cadmium cell specification that you would like to see improved, changed, deleted, etc.

<u>A</u> <u>IMPROVE</u>	<u>B</u> <u>DELETE</u>	<u>C</u> <u>ADD</u>	<u>D</u> <u>CHANGE</u>
----------------------------	---------------------------	------------------------	---------------------------

A. Improve.

1. precharge to - calculation base
2. carbonate content of the plates
3. nitrate
4. specification on separator
5. amount of electrolyte
6. seals
7. tests per mission parameters
8. terminal
9. mass spectrometry leak test
10. accelerated life test for prototypes
11. flight acceptance cycling test
12. control of carbonates and other impurities.
13. cell acceptance testing
14. electrolyte purity - low carbonate
15. detail polypropylene processing
16. plate ratio
17. seal

18. loading control
19. plate properties
20. plaque properties
21. terminal seals
22. precharge measurement
23. electrolyte control

B. Delete.

1. test spec

C. Add.

1. polypropylene spec
2. spec on carbonate content on the cell and step at which measured
3. add duty cycles on general requirements
4. seals
5. increase maximum pressure allowable in order to permit use of high levels of electrolyte to increase cycle life
6. high rate discharge (5c) at cold temperatures (0°F) or below as in situ method of detecting carbonate contamination
7. Proof tests showing electrolyte quantity is correct
8. K_2CO_3 in positive electrodes
9. decarburation procedures
10. propylene standards
11. control of carbonates and other impurities
12. cell to cell performance variations
13. control of reject rates that are allowable
14. 1.7:1 negative to positive ratio

D. Change.

1. carbonates and nitrates
2. cover x-ray exam, 99.4% Al_2O_3
3. carbonate concentration less than 3g/L
4. helium test for leaks in presence of electrolyte
5. change retention test 1.15 or 1.17
6. seals
7. electrode physical inspection
8. organic contaminants

Additional comments.

1. Spec should be on basis of performance requirements rather than on basis of material
2. The manner in which the aerospace industry procures Ni-Cd cells and batteries does not permit adequate cell characterization before use.

3. Somewhat less detail on processing that appears in current spec
4. Need to get deeper into plaque and impregnation processes
5. Needs to be tightened up in performance
6. Requires some generalization allowing options which might be appropriate to different applications - (long life vs short life, low orbit vs synch orbit)
7. Narrow down to pertinent performance and processing requirements
8. acceptance criteria for components and materials
9. Avoid adding too much. Spec is too long and should be reduced -- particularly in general and environmental areas
10. A number of question are still open
11. If possible to develop new diagnostic screening tests

II Storage.

The results of the survey on storage conditions and experience appear below. Although the 24 responses differed with respect to specific storage time or temperature, they agreed in the following ways. 1) Cells should be purchased for specific flights or purchased in one batch and activated with electrolyte as needed. and 2) the cells should be discharged and shorted during storage.

STORAGE

1. A spacecraft program consists of 5 missions, each launched on 1 year center. It is desired to obtain maximum in-orbit battery life. How would you approach the problem of supplying batteries to the program?
 - A. 11 Procure cells for each spacecraft at fixed intervals to correspond with launch dates.
 - B. 0 Procure cells for flight. Conduct cell acceptance test and place in storage, fabricating batteries as needed.
 - C. 10 Procure and fabricate all cells, but not activate chemically (KOH). Store in dry

condition under inert atmosphere, activate and acceptance test cells as needed for flight batteries.

D. 3 Other (briefly explain)

2. Under the condition indicated above, what would be the maximum period of storage allowable without impacting mission life.

Answer In Months

From question 1 above the specific storage time.

<u>A</u>	<u>B</u>	<u>C</u>	<u>D</u>
1 - 48 mo		1 - 120 mo	1 - 100 mo
1 - 36			1 - 18 wet, 36 dry
1 - 30		3 - 60	1 - 60
2 - 24		1 - 48	1 - 12-24
		1 - 36	1 - several years
4 - 12		1 - 18	
1 - 2		1 - 12	

3. What is the best method for ground storage of cells and/or batteries (non-standby status)?

- 1 low rate continuous trickle charge (indicate rate C/20)
- 4 discharged to 1.0 volt per cell or less and leave open circuit
- 14 discharged and shorted (each cell)
- 2 charged and open circuit with periodic electrical exercise
- 0 no special provision
- 5 Other (briefly explain)

4. What effect does the above environment have on battery parameters and/or life?

- 6 no effect, not significant to consider
- 4 some effect, but of no concern
- 7 large effect, significant to warrant change in philosophy
- 7 do not know

5. If you as a designer were required to obtain the maximum in-orbit battery life and could specify battery life temperature with tolerance, what would you specify?

_____ °C + _____ °C
 _____ °C - _____ °C

Number of responses:

1	-10°C	+	10°C
1	-5	±	10
4	5	±	5
1	5	±	10
1	9	±	6
1	10	±	1
3	10	±	5
1	10	+	5
1	10	±	6
1	10	±	8
1	10	±	10
1	12	+	5
1	15	±	5
2	15	+	5
1	20	±	10
1	50	±	5

6. It has been standard practice in the past to integrate flight units (including batteries) into the spacecraft for environmental testing at the spacecraft level. During the integration and testing of the spacecraft and prior to launch, the flight batteries are used intermittently typically experiencing prolonged periods of overcharge and open circuit stand. From experience, what is the average time a flight battery is subjected to the integration and pre-launch environment?

	(months)
2	1 month
1	2 months
1	5 months
1	6 months
1	9 months
1	3-4 months
2	3-6 months
1	2-12 months
1	6-8 months
1	12-24 months

CR 7540
tape+notes
LINDA -dh1

P R O C E E D I N G S

FORD: This morning we have one gentleman who would like to make some comments; apparently he's had some time to think about some discussion that was held yesterday on the separator, and he approached me this morning and said he's like a chance to comment on some of the things he heard yesterday, so at this time, I'd like to introduce Mr. Art Winski from GAF.

WROTNOWSKI: Thank you, Floyd. Art Wrotnowski, GAF Corporation.

Actually, I'm talking about Wex 1242. There was some question; this is a production item. The other -- I have five points; I'll just go down them quickly, and the other one is on cadmium migration, I'd just like to point out that this carbonate control, as practiced by Dr. King and his Canadian colleagues gave a lot of advantages of cadmium migration being one of them. I just wanted to point that out, referring to Tom Hennigan's test results, and once more I'll mention that the Aliouette 1 and 2 are still in producing -- this is as opposed to the open circuit tests that Tom observed on his cadmium migration. I just think that carbonate control may help out in this area.

Two other subjects, now, they were talking about the polypropylene stability, and it is nylon stability and polypropylene stability. We did some autoclave stability tests before we got started on the battery separator work, in which case we used a 10 percent caustic solution, and at 265 degrees Fahrenheit, and found that we had complete stability of Teflon, naturally, neoprene, and polypropylene under these conditions.

Again, that was 10 percent caustic NaOH at 265. The things that degraded secondly were -- that is, after Teflon, polypropylene, neoprene, were Nylon 11, cotton, Nylon 66, and Nylon 6, and all of the other textile fibers had no stability at all.

Dr. Fisher mentioned, or was discussing denier yesterday; the effect of denier is pretty well covered in a -- the Filtration Society, which reports their paper in the filtration and separation, the September issue, 1968, has a pore-size model for fibers which would include polypropylene structures. They assume a straight parallel arrangement of fibers, and it takes care of the denier difference, whether you're going from 1.835, as well as

dh2

the density of the structure, and you'll find that you get a considerable difference in just a single denier change.

That's all I had to say, and thank you very much.

FORD: Okay, are there any questions? Discussion?

(No response.)

FORD: Okay, to move into the subject this morning, we're going to be talking about data processing, statistical analysis, physical approach to colorative testing, and then we're going to move into the area of storage and cell test data.

At this time, I'd like to introduce John Waite to discuss new results in processing battery data. John?

WAITE: I want to take just a very few minutes of your time. I'm going to highlight some of the new processing techniques for looking at battery data; it's also been very successful in looking at medical data.

On the Air Force contract jointly with Battelle we've been trying to get a better hold on voltage, charge-discharge relationships that you can put on a computer and then use some statistics. We've tried curve fitting; that didn't work because the different environments change the curve; they've tried histograms of all kinds, and I'm sure that some things were interesting in it, but basically, the problem is, instead of looking at a data element, which is a measurement, you look at an information element.

Now, what makes an information element is really a data element associated with another one for a significant meaning. Now, in the charge-discharge for the Air Force, this is on a synchronous orbit, taking the long one, we decided that it would be nice to take some point on the discharge, and also some point on the charge, and flip these around; take this here, match it here, flip it around and take it back.

In other words, it's a hysteresis type of loop. And find out if it recovered the same way it went down. Of course, it doesn't, and if you then look at these hysteresis profiles on real data for failed cells and for non-failed cells, we found that this portion here was significantly different in this respect:

dh3

The failed ones would have a big area. The non-failed ones would have a much smaller area, so you had quite a few points to measure. So, instead of looking at just, then, the discharge, this really related to many more points on your charge-discharge curve, and since I'm not a battery man, I put this in this workshop for battery people to think about. In working with Erv Schulman in RCA, I really appreciated having an old timer look at these concepts and say, "Well, does it have a meaning?"

So I propose that you do please look at that. I have run real data on it, and it's pretty consistent when related to failed and unfailed cells.

Now this is assuming that certain defects in the cell itself will be reflected by voltage. It does seem that some of them are reflected by voltage. It might be important to find out what is the optimum orbit length to use an idea like this. Certainly the really short orbits are not going to be as effective, so you might want to change your experiment to give you the optimum orbit length, if this is a measurable criteria.

Now the other technique that is new comes out of empirical studies to crack codes. Now, the code-cracking problem is really one of -- let me get a stick over here -- is really one of comminatorial work.

If you look at Harvey Seiger's work, where he's got material research factors, you look at identifiers like General Electric, the manufacturer, you look at measurements like voltage, you can put these all together. Now, you can't put this on the computer easily to look at comminatorial studies, so you code them. Each one results in a code, the code can reflect parameters and levels.

Then when this is coded, they all start out in one bin, like this -- so that one line, and this line, this is only representative. This line gets to about 50 characters long. One line would be a filter or a reduction of the data known on this cell.

Now, you take these techniques and you start sub-setting it by things that you know. You know that these relationships must be -- you subset it, and it starts making other bins. These all have properties due to known facts.

After you've run this through until where you then search mathematically to find factors that appear in here that

dh4

you don't know. These are relationships associated with ones that are known, and when you finally can't get any more changes, you retranslate it back into meaning.

Now this particular application was a drug analysis. They claim the drug does certain things. So you write up all the claims, run through here, and you'll find here they had deaths in these areas, this drug did not get passed by the FDA.

But here you'll find that these claims are 100 percent significant, and very good. So, this routine has picked out, said "Your claims are wrong, this is what you should be claiming, and your data will confirm it statistically."

Then you go to your statistical model, and you can get your clearance. Now, I think this technique should be looked at for battery work, because you can relate the research with the tests, with the environmental, with the test, actual cycling test, life test, and come up with some information that this battery scientist can then interpret.

It's a discipline that takes a lot of work on the mathematician side, and I do feel that the progress comes from two technologies getting together, and helping each other.

So thank you very much.

(Applause.)

FORD: Any questions? Discussion?

STEINHAUER: Steinhauer, Hughes.

WAITE: Yes.

STEINHAUER: On your hysteresis loop on the synchronous orbit, is it necessary for that type of analysis to take the cell or battery over the knee of the curve, or will it work by studying it within the range that you normally would use at say 50-60 percent depth?

WAITE: We gained that. It's very important which points you take; I didn't want to go into that, and we've found by gaming it that the most reliable part was dropping off the end of discharge and the top part of charge and the top part of discharge, taking the middle portion.

I think that maybe if more care is taken in getting

dh5

the data, you might want to take more of the curve. That's as far as we went, but I do think it has quite a lot of potential; needs some extra work done on it.

FORD: Okay, thank you, John.

Okay, at this time, we have one presentation that we'd like to pick up that we did not have time for yesterday. The subject is nickel-cadmium cell magnetic properties. John Rubenzer from NASA-AMES

RUBENZER: One word before I go into the nickel-cadmium subject. Yesterday, at the end of Chuck Palandati's presentation. One member of our group asked a question concerning, as I recall, what cells we would be using in the silver-zinc batteries that Chuck talked about, and I sort of copped out an answer by saying, if you want some information, write our program office.

I sort of assumed that you would be somewhat familiar with the -- our predicament, which was incorrect on my part, so I'd like to give you a very quick shot at why I answered the question that way.

I'm at Ames Research Center on the Pioneer-Venus study team, and at the present time, we have two prime contractors performing a design study, or what we call the phase B of the contract, and these two contractors are in competition with each other, and as a result of this, we are most careful in what we say about what batteries we'll be using, not only batteries, but any hardware in a spacecraft; spacecraft design features, mission operations -- anything along this line which might prejudice or bias in one way or another either of these contractor designs. We want as pure a study from them as we can get.

We realize that we, like most people, have pet subjects, or favorites, both in design and philosophies, so we try and keep our mouth shut as much as we can, to minimize affecting their studies, because that's really what we contracted with them for; to find out how they think, not how we would do it.

So anyway, my answer has to remain the same. I'm sure you won't feel bad, because we probably don't know at this point anyway. Now we'll get into a little bit of work we did on nickel-cadmium cells; we're in the process -- could I have the first --

(Slide 89.)

dh6

About a year ago, as a result of some discussions between Eagle-Picher personnel and some magnetics test people at Ames Research Center concerning possible batteries for use in spacecraft for long duration missions, planetary -- interplanetary missions. The nickel-cadmium cell as well as silver-cadmium, silver-zinc, et cetera, were discussed, but we were looking at batteries that we would be using on spacecraft that carried magnetometers as experiment hardware, and of course, as you're I'm sure well aware, nickel-cadmiums are a bit of a magnetic beast, and we're talking about pretty clean spacecraft.

And as a result of these discussions, it was suggested that perhaps a nickel-cadmium cell could be packaged in Mumetal in place of one of the more standard materials used in a case, specifically, in this instance, stainless steel.

So a few months later, the Eagle-Picher representative delivered to Ames two cells which were identical to their 8 ampere-hour cell, sealed cell, that they package for space applications, typically, only they weren't cased in Mumetal. He also gave us two other cells which were identical. except they had the standard -- can you slide it up just a tab?

The cell case data is given down here, the thicknesses and the 304 L stainless steel case, et cetera. This viewgraph generally shows the construction of the cell which is standard in most respects. Again, the case is Mumetal, and on two of the cells -- and on two stainless steel.

So we gave these to our magnetics people, and took a look at them magnetically. The results of this look are on this viewgraph.

(Slide 90.)

It turns out that in casing a cell in Mumetal, produces rather impressive results. As you can see on this slide, our magnetics people took all their measurements at 50 centimeters from the geometric center of the cell, the axes are identified as shown in this sketch.

Where people initially exposed the cells to 25 gauss field, and took measurements along the three axes, which are listed here, and then degaussed the cells with a standard degaussing procedure of -- as I recall, these diminishing AC field, and remove whatever remnants they can from the cell -- it's sort of standard procedure.

dh7

So anyway, they expose the cells to a field and then deperm them, and the results are as shown here -- after a 25 gauss exposure, the Mumetal cased cells were considerably lower in their magnetic signature than either the stainless steel, and then also one cell that I took and took the stainless steel case off of. I removed not only the case but the cover, and left everything else on the cell, and-- oh, and I took off this fill tube, which turns out was a non-magnetic stainless also, so we can sort of forget about the fill tube. That's a little note added on the bottom.

Then they deperm the cells and the signatures were as shown here. It's an order of 10 for the post deperm remnants and as you can see, 2 to 3 to 4, and sometimes more in the Y component, which turned out to be minimum for the 25 gauss exposure.

Okay, let's look at the next viewgraph.

(Slide 91.)

In terms of spacecraft utilization, I just ran through some numbers briefly, and used some rough and dirty scaling factors, but generally for these three cases, if we consider a 25 cell battery, which is probably more than we've ever used, but sort of a worst-case condition, or design as far as the number of cells is concerned, we would end up at the end of a 10 foot boom, which would be roughly 12 feet from the battery, because we want to locate the battery as far away from the magnetometer head as possible, so you put them in the other side of the center line of the spacecraft, diametrically opposed from the magnetometer.

So, I used a 12 foot boom length, which is not too difficult to design or achieve, but I sort of picked the number out of the air. It's not fixed in any case; you can substitute what ever number you want. But using the tenth of a gamma remnants shown after degaussing in the previous viewgraph, we would end up with the remnants of five thousandths gamma at the end of a 12 foot boom, which is mighty low, but that's kind of optimistic, because that's with a total degauss, and you always pick up some perming as you launch and handle a spacecraft for whatever environment.

In case number two, the four and a half gamma used was the post-25 gauss exposure, which certainly is worse case, because there's no way on earth the thing is going to perm up to, you know, a 25 gauss field. As a matter of fact, earth's

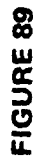


FIGURE 90

ESTIMATE OF REMANENT FIELD DUE TO NI-Cd BATTERY
AT MAGNETOMETER (~10 FEET AWAY FROM SPACECRAFT)

1. ~25 CELLS (M-H) $\times 0.1 \text{ y} = 2.5 \text{ y} \times 70\%$ (SCALING FACTOR) =
1.75 y AT 50 CM (50 CM = 1.65 FEET);
THEN FIELD AT END OF 10-FOOT BOOM (12 FEET FROM BATTERY) WOULD BE ABOUT 0.005 y.
2. USING 4.5 y IN PLACE OF 0.1 y IN (1), WE GET ABOUT 0.21 y INSTEAD OF 0.005 y.
3. FOR LAUNCHING IN EARTH'S FIELD OF ~5.0 GAUSS, WE CAN ESTIMATE WORSE CASE PERMING AS FOLLOWS:
25 CELLS $\times 0.9 \text{ y}^* \times 70\% = 15.7 \text{ y}$ AT 50 CM;
THEN FIELD AT 12 FEET WOULD BE ABOUT 0.041 y.
ACTUAL FIELD AFTER LAUNCH SHOULD BE LESS THAN 0.041 y.

*4.5 γ AFTER 25 GAUSS EXPOSURE SCALES TO ABOUT 0.9 γ ($\pm 15\%$) AFTER 5 GAUSS EXPOSURE.

FIGURE 91

MAGNETIC REMNANCE TEST OF EAGLE-PICKER IN-CD CELLS

CELL S/N AND CASE TYPE	Magnetic field remnance at 50 cm from geometric center (peak gauss)					
	Post 25 gauss exposure			Post deperm		
	Z comp.	Y comp.	Z comp.	X comp.	Y comp.	Z comp.
S/N 221 MUNETAL CASE	10.0 γ	4.0 γ	23.8 γ	0.2 γ°	-0.1 γ°	4.0 γ°
S/N 223 MUNETAL CASE	13.5 γ	4.5 γ	21.8 γ	-0.3 γ°	-0.1 γ°	2.5 γ°
S/N 209 STAINLESS CASE	177.5 γ	10.0 γ	181.5 γ	10.0 γ°	1.0 γ°	8.0 γ°
S/N 220 STAINLESS CASE	187.0 γ	12.8 γ	130.5 γ	8.0 γ°	1.0 γ°	5.0 γ°
NO S/N CASE REMOVED (Fill tube removed also)	150.0 γ	9.8 γ	156.0 γ	7.0 γ°	1.0 γ°	5.0 γ°

Deperm remnance can be reduced to essentially zero by "breeding."

(60 Hz A.C. degaussing)

dh8

field is somewhere around 5 gauss.

So in the third case, I used the 5 gauss as a typical field, and estimated -- I call a worst case, I guess I should say the real case -- with a 25 cell battery, and scale the perming to match typically a 5 gauss field, figuring it permed as much as possible during launch, and used the 70 percent, which is a scaling factor, when you take single cell data and stack them up. It's not additive, so you have to throw in a number which I got from our magnetics people, and apparently, it's proven to be a fairly accurate number.

Anyway, to make a long story short, we would end up with a field less than .041 gamma, which is quite low. It's amazingly low for a nickel-cadmium battery, and in looking at these numbers, it turns out that if we could make an estimate of what the actual remnants of such a battery would be after launch -- this is once you achieve orbit, or burnout of your last stage, we'd guess that the remnants would be somewhere on the order of 2 hundredths, of .02 gamma, which is very low.

To give you a reference number in this, if you're interested, on the Pioneer 10 spacecraft, which is on its way to Jupiter, the total measured remnants at the magnetometer head was -- I believe it was .03 gamma, and that was a very clean spacecraft. A lot of money was spent making it clean. And that particular spacecraft, which has typically a two year trip time, and it's a swing-by mission for those of you who aren't familiar with it, they use silver-cadmium cells with rather extensive cell protection, cell charging, cell isolation, the battery pack is -- I don't remember the exact numbers, but it's roughly at half electronics, so you pay kind of a nasty price when you start flying that sort of cell for a long mission.

As a result of these tests, we have ordered from Eagle-Picher, 28 nickel-cadmium cells, encased in Mumetal, as were these cells, with sponge-negative electrodes to further reduce the nickel content and subsequently, the size of the cells. If we crank this factor into some of these numbers, it'll probably come out a little less than .02. The reason we've ordered the cells, or the primary reason is, we're going to take them to our magnetics facility, and start playing with them like a bunch of Dominoes, and stacking them up, and find out what the minimum, or what the optimum cell configuration will be to minimize the remnant field in the axis on which the magnetometer would be located.

dh9

This information, although originally wanted for consideration for various planetary applications, turns out looking rather interesting in regards to our Venus Orbiter Mission yesterday, Chuck Palandati talked about the Venus Probe mission. That is one of two types for the Pioneer Venus mission as presently envisioned. The second is an orbiter. An orbiter mission of Venus involves a trip time of roughly three months, and it is then inserted in orbit above Venus. The orbital parameters have not been set; they will be a part of various studies, but typically it'll be somewhere in the neighborhood, perhaps, of a 24 hour orbit.

And it will be designed to remain in orbit for a Venus-sidereal year, which is like 225 earth-days. So, it has to last pre-launch, three months to Venus, and then 225 days in orbit minimum. So we will take these cells when we get them, roughly in a couple of months, and find out what they look like when we stack them up in battery configuration, and hopefully come up with some good numbers.

If any of you have any question regarding, or are curious as to what the cells look like during a coffee break, we have a couple cells which Earl Carr brought along. Some of them -- one of them is one of the cells we tested, and its twin in stainless steel and the sample of the extruded cases sitting on the table over here -- I guess they're blocked from your view by the briefcase, but you can take a look at them.

That's all I have.

(Applause.)

FORD: Thank you, John.

Questions?

CHARLIP: Steve Charlip, Gulton

Can you tell me what the alloy Mumetal is? This is a tradename by Inco. What is the generic alloy composition of Mumetal.

RUBENZER: I knew you'd ask something like that, so I asked Earl to be on standby, and he can give you those details. I honestly don't know.

CHARLIP: I have another question. You have made a -- I believe it's not quite a realistic comparison between

dh10

Mumetal and stainless steel, because you've used Type 3 or 4, which when welded and worked, precipitates ferrites, and becomes slightly magnetic. May I suggest that you do, if somebody would try and do the same comparison using Type 310 stainless steel, which austenetic even during working and welding. And I think you may get a more realistic comparison between stainless steel and Mumetal.

CARR: This is Earl Carr of Eagle Picher.

First of all, from John's data, I dispute that, because -- John, can you put the slide up? Which shows the five different cells?

RUBENZER: Certainly.

(Slide 90.)

CARR: I can't read that from way back here, but there is one cell, which is the bottom cell -- is that right, John?

RUBENZER: That's correct.

CARR: Which has no case at all. And the numbers for that particular cell are very close to the two cells that are encased in stainless steel. So the contribution of the case itself seems to be very little. Is that true, John, from the data?

RUBENZER: It looks that way.

CARR: The Mumetal is primarily a nickel alloy. I don't remember the exact composition. The only thing that is of any major concern to us is that it has some copper in it -- approximately 3 or 5 percent copper. It's I think in the order of 65 percent or so nickel, and then there's some iron and some chromium.

RUBENZER: Earl, do you make a stainless case of the alloy the man referred to, of 310?

CARR: I'm personally not that familiar with the different stainless steels, but I don't really see why not, so that we could do this, and I'm sure that -- well, these parts are deep-drawn cases, but I'm certain that it could be also made with other alloys.

RUBENZER: The reason I asked him that really is,

dh11

in taking a look at this Mumetal in case L, we just took standard off-the-shelf type cells which were readily available. We made no attempt to pinpoint the optimum stainless steel, the alloy to use, or anything along that line.

CHARLIP: Let me answer Mr. Carr. Some years ago, a company I worked for built some cases made of three or four fully annealed stainless steel, which Tom Hennigan's group tested for magnetism and found them slightly magnetic. On the other hand, we also sent some cases made of Type 310, which is a higher nickel-chromium alloy, and they were almost nil. So I just suggest perhaps this may take the place of the nickel-copper alloy which is more expensive, much more difficult to fabricate than Type 310 stainless steel.

STROUP: Stroup from Goddard. What does that gamma mean, quantitatively. In terms of gauss. That's one question. The other question is, I wonder, do you have a technique for compensating for the current that is going out of the battery during operation.

RUBENZER: Okay, we're going to look at that. We have a few ideas again on the current compensation question I'm addressing now. We have no great godawful schemes in mind, but a few ideas which we're going to try also.

First we're going to look at just straight remnants with no current flow at all. But the reason I haven't worried about current flow is whether we use silver-cadmium, zinc, or nickel, it's going to be pretty much the same. That problem is more or less standard regardless of the type cell we use.

If that's satisfactory, a gamma, as used in our work is equal to 10^{-5} gauss. It's just a smaller unit which is used quite frequently, and I thought quite extensively, but perhaps it isn't as extensive as I thought.

GROSS: Sid Gross, Boeing. We've had magnetic problems and tested nickel-cadmium cells. We found the cells had what we thought was an unacceptably large magnetic effect, and then decided we probably had to do something about that, and tested all the complements in the cells, the plaques and the plates and the covers and the cases, and so forth, and we found that we couldn't predict the cell magnetic effects from the components. But we found that all the cells were about the same effect, then we built batteries and found we couldn't predict battery effects from cell measurements.

dh12

And we found out that -- we think we know some of the reasons why; we haven't -- I don't want to go into that part of it. But the big problem was not really what the magnetic effect is, but whether or not it stays constant. If you have a battery that it's moderately magnetic, that's no great sweat to most of the experimenters, because they can compensate for it. But the problem is to keep it constant, and this, the biggest problem there is during the launch. Because you're passing through a magnetic field, and the battery's undergoing vibration, and this is very difficult to predict.

RUBENZER: Okay, you're point's well taken. I'd comment on it, but I'm afraid we're getting into this area again where we don't want to prejudice the design work being done by our two contractors. They're each looking at this problem; independently I'm sure -- in fact, I'm positive of it, and well, it's the same sort of thing. We just don't want to bias their design work by throwing in any ideas along our -- that we might have.

But you're point's well taken, and it certainly will be looked at. Tell me one thing, though, did you find when you configured the cells into batteries, did you find the batteries were repeatable, even if you couldn't scale a battery effect up from cell data, or --?

GROSS: We didn't test that many batteries, but in general, it was.

RUBENZER: Okay. Thank you.

FORD: Next question.

STEINHAUER: Were these two cells taken apart, namely the concern with the copper, any problems?

RUBENZER: I'm not positive, but I'm quite certain they have not been disassembled. I know one of them has them. It's up here.

Earl? I presume both of them are still assembled, you haven't taken either of them apart yet?

CARR: Right.

RUBENZER: When we get our 28 cells, incidentally, we'll repeat the testing on the two cells that we've tested already, and I hope also the stainless cells, just to make

dh13

sure that our data's repeatable, and --

STEINHAUER: We'd be interested, of course. The Mumetal is a common material used in the vacuum tube field, where you're using high course of force materials. It is a shield type material. So it's not unusual that this occurs. I guess my question is, you're getting in these 28 cells, will that data be generally available?

RUBENZER: Oh, yes. When I cop out with one of these program office type answers, I don't really mean to cop out, but whenever we get information, we disseminate it. We're not trying to keep any secrets. It's just that we don't want to make problems, and if you ever work for Uncle, you find out that if you say something at the wrong time, you can get in a lot of trouble.

(Laughter.)

WERTHEIM: Wertheim, Grumman. Just one clarification, John. When you made the measurements that are indicated in the chart you've got up right now, was the cell operating?

RUBENZER: It was not.

WERTHEIM: Thank you.

RUBENZER: No, no current flow at all.

GROSS: May I make a small correction of what I said earlier. I said you can't predict battery magnetic effects from the cells. What I meant to say is you can't scale up directly. You can predict.

RUBENZER: Okay. Which is what we suspected a little bit, and was one of the reasons that we thought it was worth buying 28 cells to continue looking at this. It looks good enough for that, anyway.

MAUER: Mauer, Bell Labs. Why don't you simply put a Mumetal shield around of all 28 cell battery of standard cells?

RUBENZER: We might try that, but I can't really answer your question, because I wasn't in on the original discussions when it was decided to try this approach. But I think Earl can, because he's got his hand up.

CARR: Earl Carr, Eagle-Picher. There's a lot of

dh14

things that can be done that we think -- this represents the first crack at something that we thought was interesting. For example, a typical nickel-cadmium cell has a lot of protruberances on the cell. The terminals -- there's just a lot of bad areas, and there's design work that can be done on a cell to optimize it with respect to these -- I guess I call them "eddy" areas, and then in addition, the battery work is very definitely a promising area to reduce the -- a very simple mumetal foil, as Dr. Mauer has suggested, is certainly a thing that could be done to further reduce this -- the magnetic properties.

So what we thought was we would start here, and the cells that John is going to get will be used for -- like you say, a Dominoe exercise to see how the thing works when it's put together in various ways, and then beyond that, there are these other packaging techniques that can be used.

So I think it's very promising, and I think it's real good and new information.

RUBENZER: Once I get the cells, I can wrap Mumetal around all of the cells, but it's kind of tough for me to take the stainless cases off and put Mumetal on in place of them, and so I took the easy way out. We'll play with everything we can think of.

HENNIGAN: I just wanted to mention here that --
I just wanted to mention here that it's been about 12 years that we've been flying these non-magnetic batteries, and designing them here, and so forth. I just hope the contractors bidding on this don't try to reinvent the wheel again.

Thank you.

KLEIN: Klein, Energy Research. Did you map just an empty Mumetal case with terminals?

RUBENZER: No, we did not. We didn't have one. I don't know if we would have if we had.

FORD: Let's take one more question. Bob?

STEINHAUER: Steinhauer, Hughes. If the copper's all right in the case, how about sponge Mumetal plates?

(Laughter.)

dh15

RUBENZER: Well, I'm not going to answer it.

FORD: Okay, thank you, John.

The next subject we have for this morning is a physical approach to accelerated life test, by John McCallum with Invention Talents, Incorporated. John?

MC CALLUM: During the past several years, I've been privileged to work in the area of trying to develop accelerated life tests for spacecraft batteries. As you can gather from the content of the meeting, this is a very complicated situation, and there are many ideas about how this should be gone at or indeed, whether there's any hope of doing something like that.

Basically, when I was at Battelle, we assumed that there were three general approaches to arriving at an accelerated life test. And one we called an "empirical approach," in which you try this, or you try that, or you look at the data to see what the data will tell you.

John Waite here mentioned to you some of that kind of work. There have always been empirical tests, and I suspect there always will be.

The second major approach to arriving at such a test is statistical, and in this particular approach, you list the various kinds of variables, independent and dependent, and run your regression analysis or some other -- use your other statistical tools to arrive at interaction coefficients between these various variables.

We had a paper here yesterday where someone studied the processing variables, putting together a battery that way, and it requires very many samples, and you again try to find out what the data will tell you.

The third main approach that we have delved into is what we call a physical approach where we try to get at the mechanisms of failure and what's going on in these batteries and that particular approach has been my main interest, and so as we discussed the aspects of aging and why battery performance degrades, we got into the use of the concept of stress and it seems as though most men will accept the idea that if you can stress a battery or if you can stress a man, that you can age him faster, or that you can bring about this aging process.

dh16

And so the question that we addressed ourselves to was just what is meant by stress, and how many are there, and how do they relate to one another from a physical viewpoint.

Now may I have the first viewgraph?

(Slide 92.)

I have, from a recent report on stress-strain modeling, in the left hand column, four kinds of kinds of energy: Mechanical, electrical, thermal, and chemical. And in this one table, I propose to you that there are all the physical stresses that are involved in batteries.

In the next columns 2 and 3, there are listed the amount factors and intensity factors, and I bring those up because one of them, specifically the intensity factors, are related to stress, and amount factors are related to strain or strain rate, and so there came to be quite a bit of discussion about, well how do you tell the difference between these factors in each energy form, and in Row 3, where we list thermal energy, you'll see I've got two amount factors or intensity factors because temperature is an oddball when it comes to trying to fit it into this scheme.

Anyhow, in the next two columns, we have the spring analog, in which stress is proportional to strain, Hook's Law in the first row, mechanical springs. In the second row we have the electrical analog of the spring, which is typified by capacitors, or in the case of a battery, we can expect to stress a battery by a depth of discharge.

In the next column we have thermal stress, and strain, and finally chemical stress and strain in the bottom row, wherein concentration or more precisely, we ought to be talking about the chemical potentials, but nevertheless, the spring analog has to do with chemical kinetics.

In the 6th and 7th columns, we have the dashpot analogs in which, if you multiply the stress times the strain, you end up with dimensions of power per unit volume. And these dashpot analogs are kind of interesting, because an ideal dashpot always dissipates and never stores anything. And when you start talking about dissipation, we're talking about what's the matter with a battery. You would like your battery to be an ideal spring and store energy and get it back, but your dissipating forces show up with dashpot analog.

dhl7

And in the second row, you have Ohm's Law, third row, you have Floray's Heat Conduction Law, and in the last row, you have fixed diffusion laws.

Now, I propose to you that in various combinations of those stresses and strains, and there's quite a few in that table, that there are all the stresses and strains involved with aging and loss of performance of batteries. So, having proposed that, I guess the real question that we've been trying to answer with discussion and experiment was first of all, is this framework acceptable? That is, would men like yourselves in this room accept this way of looking at an accelerated life test?

So in the next slide, we -- Tom, if I could have the next viewgraph.

(Slide 93.)

This was one that kind of interested a number of people, where we -- if you take the spring analog, you have temperature as your stress, and if you take the dashpot analog, you have temperature gradients, and so the question has come up a number of times: Is it temperature that affects a battery, or temperature gradients?

And in this particular result I'm showing you, we had supposedly identical cells, except that in one set, there were heaters inside to maintain a constant temperature on one side of the cell, while the environmental temperature differed. And in the cells without temperature gradient, we went from a minus 20 to a plus 40 Centigrade, and we measured then, a degradation rate on these cells with and without temperature gradients, and it turns out that there is a faster acceleration of wards failure with the temperature gradient than without it.

(Slide 94.)

In the next viewgraph, we have Roman Numeral III cells and Roman Numeral IV refer again to two sets of cells at five stress levels, at different rates of discharge. And the rate of discharge shows up in the first table I showed you, as dashpot analog.

And again we have these cells, two sets of 25 cells each, 5 at each stress level, with and without a temperature gradient. And the four cells had the temperature gradients and the three cells did not. So, with the one exception there,

dh18

namely Roman Numeral IV-IV, which fell down in here, we subsequently found out there was something the matter with the heater so it too turned out to be where we had thought it might be.

(Slide 95.)

The next slide -- Now, continuing our efforts to show whether this framework is acceptable, those first two experiments I showed you were on demountable cells, using some commercial electrodes, and now we're going to try to verify this with some commercially-sealed cells, and so we repeat the rate of discharge, and we have introduced another one which comes out of the table of stress-strain relationships, and the -- what's called a charge-strain rate, and you'll see that the charge-strain rate being charged at different short times to high times, but discharge at a one hour rate, and in this discharge, we're discharging them at higher and higher rates, shorter time, but charging them at a constant, one-hour rate.

This test has just been started, and I don't believe results are in on it yet.

(Slide 96.)

The next slide shows another set of experiments that have been recommended, but have not been started. This particular recommendation includes a combination of a temperature gradient with a high discharge rate.

(Slide 97.)

The next slide. This now shows some experiments that I understand are under discussion for future work at Crane, and you'll find that under these factors; there's eight of them. But the various temperature levels, the depth of discharge, the charge rate, the discharge rate, and the percent of overcharge are five factors that grew out of this physical framework of how to accelerate the aging of sealed cells.

Now, in this particular program, there is a great deal of emphasis being given to this statistical approach, and fractional-factorial design has been worked up, and they'll be after their interaction coefficients. The empirical approach will be applied to this data analysis, and is being applied to some of the planning of, "Let's try this, let's try that."

SUMMARY OF GENERALIZED STRESS-STRAIN
AND STRESS-STRAIN RATE RELATIONSHIPS

(1) Energy Form	(2) Applied Factor	(3) Intensity Factor	(4) Spring Analog of Strain	(5) Spring Analog of Strain Rate	(6) Displacement Analog of Stress	(7) Displacement Analog of Stress Rate	(8) Initial Stress
Row 1 Mechanical	Volume, V	Pressure, P	dV	$\frac{dV}{dt}$	dP	$\frac{dP}{dt}$	P
Row 2 Electrical	Charge, Q	Voltage, E	dQ	$\frac{dQ}{dt}$	dE	$\frac{dE}{dt}$	E
Row 3 Thermal	Heat, q	Temperature, T	dq	$\frac{dq}{dt}$	dT	$\frac{dT}{dt}$	T
Row 4 Chemical	Matter, M	Concentration, C	dM	$\frac{dM}{dt}$	dC	$\frac{dC}{dt}$	C

(a) Energy forms associated with performance and aging of material

(b) Generalized displacement

(c) Generalized stress

(d) Generalized strain

(e) Generalized strain rate

(f) Generalized stress rate

(g) Generalized concentration

(h) Generalized concentration rate

FIGURE 92

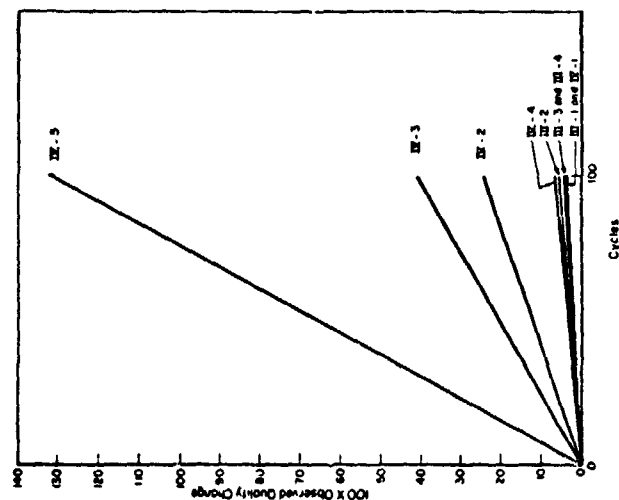


FIGURE 94

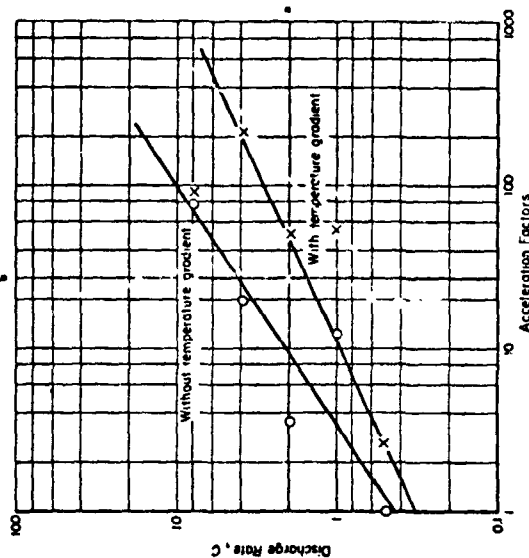


FIGURE 93

Group No.	Charge Current Step 1, amp	Step 2, amp	High Charge Time, min	Discharge Current amp	Discharge Time, min
Charge Strain-Rate Test (20 amp-hr Cells)					
C-1	48.0	2.0	9.4	7.5	60.0
C-2	24.0	2.0	18.8	7.5	60.0
C-3	12.0	2.0	37.5	7.5	60.0
C-4	6.0	2.0	75.0	7.5	60.0
C-5	3.0	2.0	150.0	7.5	60.0
Discharge Strain-Rate Test (6 amp-hr Cells)					
D-1	3.0	0.6	60.0	3.0	60.0
D-2	3.0	0.6	60.0	6.0	30.0
D-3	3.0	0.6	60.0	12.0	15.0
D-4	3.0	0.6	60.0	24.0	7.5
D-5	3.0	0.6	60.0	48.0	3.8

FIGURE 95

dh19

The physical approach is also going to be looked at, mainly through the Air Force and Gerald Miller, and John Lander, and some others, and so it's my hope that when this program is through, that the physical approach is not only acceptable, but we'll find it to be preferred.

So that's it.

(Applause.)

FORD: Questions?

STEINHAUER: Steinhauer, Hughes. I think this approach is very definitely desirable. My concern is that once you get enough data, when you stress a single component of a cell, we know how to make it fail, or to make it fail more rapidly, but how do you know you're experiencing the same kinetics that you would have in a real situation in particularly interactive rates of failure?

MC CALLUM: I think the vital part of the physical approach is failure analysis, and post-mortems, and an understanding of why these cells failed, and there is no valid accelerated test, whether it's empirical, statistical or physical, if you've made a cell fail for a different reason than it would normally fail under, it's an invalid test.

So I think the answer to your question has to be a physical examination.

STEINHAUER: Can the problem be handled -- let's assume you can't get enough data by the physical examination. Can the problem be handled in any way by mathematical or statistical treatment to separate out whether you've got a different situation occurring?

MC CALLUM: I think there is. The evidence is not quite as convincing that way, but if you look at life test data on electronic components, and other physical -- usually, you'll find an erroneous type of plot or logarithmic relationship between the stress and some log strain relationship.

If you have the same mechanism, say over five stress metals, this relationship ought to be a straight line. If the mechanism is changing as you go up there in stress level, you'll find that the things -- you get a curve, or it just doesn't fit that kind of plot. And I think that's pretty fair evidence that the mechanism did not change.

dh20

RAMPEL: Rampel, General Electric. I'd like to suggest one other factor be added to that table, and that's electrolyte concentration.

MC CALLUM: Concentration's in there, and --

RAMPEL: I didn't see it.

MC CALLUM: It was in chemical.

RAMPEL: The last slide?

MC CALLUM: Oh, the last slide? Oh yes. That's the eight factor experiment you're talking about now.

FORD: Move to the last slide, Tom.

(Slide 97.)

MC CALLUM: Well, you want to tell him about it? He thinks that ought to be changed.

Are you talking about the additional electrolyte, or you're saying that there ought to be different concentrations of electrolyte?

RAMPEL: Yes.

MC CALLUM: You want to comment on that, Tom?

HENNIGAN: We took out the plate loading, and put in a concentration. Okay?

(Inaudible response.)

HENNIGAN: Oh, okay.

MAURER: Maurer, Bell Labs. I'm not sure I understand your experiment with temperature gradient. How do you separate out the effect of -- that the cells exposed to the temperature gradient are really operating at a higher average temperature than those without the gradient? I would think just an off-hand look at this that the cells with gradient would always fail faster because they're operating at a higher temperature. Average. At least, half of the cell is.

MC CALLUM: No, we had -- I don't think that would have followed in this particular experiment. We had these in environmental chambers, say at 40 degrees Centigrade, so the

"Summary of Cell Experiments"

I. OBJECTIVE: An objective of these "Cell Experiments" is to acquire cell physical data and cell performance and life data under various factors and levels of stress.

II. FACTORS AND LEVELS

Factor	1*	2**	3***	4***	5*
Temperature, T (°C)	20	30	40	50	60
Depth of Discharge	20	40	60	80	100
Charge Rate	c/4	c/2	c	c	4c
Discharge Rate	c/2	c	2c	4c	8c
Percent Charged	110	140	170	200	230
Plate Loading (x)	50	60	75	90	100
Precharge (z)	0	10	25	40	50
Additional Electrolyte (cc)	0	0	3	5	5

III. FACTORIAL COMPOSITE DESIGN

- Factorial Point $1/4 \times 2^8 = 64$ packs (5 cells/pack)
 - Star Points $2 \times 8 = 16$ packs
 - Center Point $1 = 5$ packs
 - Normal Conditions 4 using temp. & per cent recharge as variables
 - Cells for tear down examination under cycled, uncycled, 75 cells cycled and removed
- * Star Point Levels
 ** Factorial Levels
 *** Center Point Levels

Note: These Cell Experiments are not to be conducted within this program. Appropriate cell data will be made available by the Air Force throughout this program.

FIGURE 97

Group Number	Chamber Temperature, C	Induced Temperature Gradient, C	Charge Rate		Discharge Current, * amps	Discharge Time, min
			Step 1	Step		
1	20	none	C/2	C/10	5	35.0
2	"	"	"	"	10	17.5
3	"	"	"	"	20	8.8
4	"	"	"	"	40	4.4
5	"	"	"	"	80	2.2
6	20	40	C/2	C/10	5	35.0
7	"	"	"	"	10	17.5
8	"	"	"	"	20	8.8
9	"	"	"	"	40	4.4
10	"	"	"	"	80	2.2

* Depth of discharge should be 48.7 percent for all groups.

FIGURE 96

dh21

cell would be the same inside and out. Would be one point.

Now, on another point, you'd have environmental temperature say at 20 centigrade, and one cell would be 20 degrees inside and out. The companion cell would have a heater inside which maintained the temperature at 40 inside, at least at the heater, and 20 outside, and thereby we have a gradient. And so on as you go down, we maintained the inside temperature of 40 in the particular set, the external would be at minus 20; one cell would be -20 inside and out, and we checked that this was so. A companion cell would be minus 20 out, but the heater would be at 40 inside.

MAURER: So the average temperature of that cell with a gradient would be substantially above the cell without the gradient.

MC CALLUM: That's true.

MAURER: And so it would naturally fail faster.

MC CALLUM: True, but it would not be above the average temperature, say of 40 and zero -- the average temperature would be 20. It certainly shouldn't be any different than the cell at 20 in that case. But it is. There is definitely a difference.

HOLLECK: I think if I recall right -- Holleck from Tyco -- from the report, the cells behave similar to the cells which were cycled at 40 degrees. The cells with a temperature profile behave similar to your cells without temperature profiles cycled at 40 degrees C.

MC CALLUM: I think this is a matter of degree; There were, on one of slides, acceleration factors of 30, something of that order, and I think one of the surprises to us was that the effect of temperature was not very large in these particular cells, and within a factor of two, your answer's correct. But not absolutely correct.

FORD: Are there other questions? Comments?

(No response.)

The next topic, in fact, the next three topics that we have to discuss is on storage effects. The first one by Sidney Gross of Boeing. That will be followed by Jim Dunlop of Comsat, and the third on storage I will present myself. Sid?

dh22

GROSS: First slide, please.

(Slide 98.)

This is just a fairly quickie. I pulled this discharge curve out of the archives, showing the end of discharge voltage on an old battery, the Lunar Orbiter, which -- this is telemetry data on the battery, which is 12 amp hour cells per battery. And the reason to show the chart is to, just to add to the archives of demonstration that there is in the older cells, a significant memory effect. The particular orbit was a 3 and a half hour orbit with .9 hour discharge at a 35 percent depth of discharge at approximately 90, 95 degrees, in this particular case.

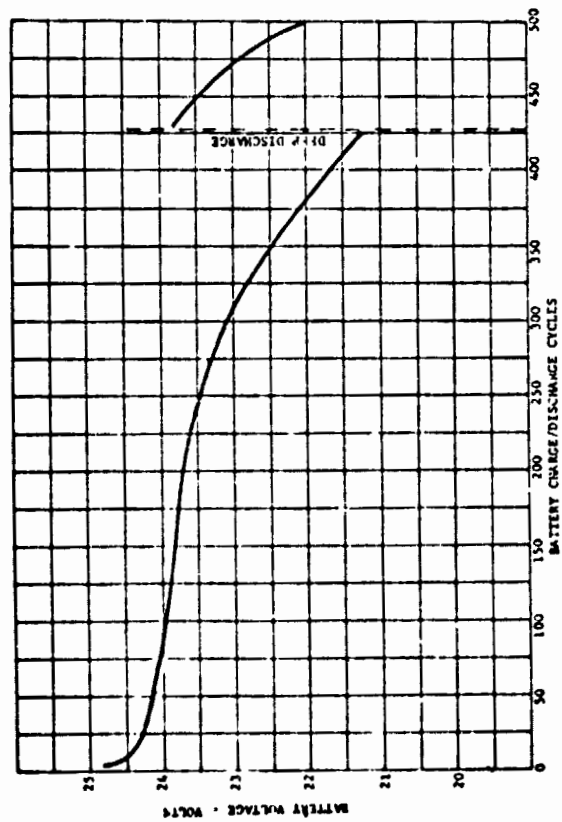
At about 420 cycles, the battery was subjected to a fairly deep discharge, somewhat uncertain, but in excess of 70 percent depth. And we obtained, -- at that point, when the battery voltage was just a little bit above 21 degrees, this was done deliberately in order to get a few more cycles out of the battery, because we're right at the limit of the minimum allowable voltage. And we did get enough extra cycles before the planned lifetime, which was about 525 cycles -- the curve stops slightly before the Orbiter was deliberately crashed onto the moon.

But -- the first point is that in the old cells, there is definitely a memory effect. I've heard people say that they're not sure whether there was a memory effect or not. Secondly, I think that you can see that the performance of these cells is really not very good, compared to today's standards, and I think that most people agree that there has indeed been improvement in performance with today's technology.

The second slide, please?

(Slide 99.)

On this slide, we're plotting the cell discharge voltage at .2 second, as a function of the discharge current. These are for 7 ampere-hour cells. There are two groups of data; one is for cells that are fully charged and have not undergone any storage at room temperature, and the second group is for cells that have been fully charged and stored for six weeks at room temperature. The purpose of this was to provide information on the effect of using batteries for firing squibs, and the batteries that are on the launch pad always have a certain amount of storage life on them. And the first task that the battery has to perform is almost



END OF DISCHARGE VOLTAGE — LUNAR ORBITER LO-1

FIGURE 98

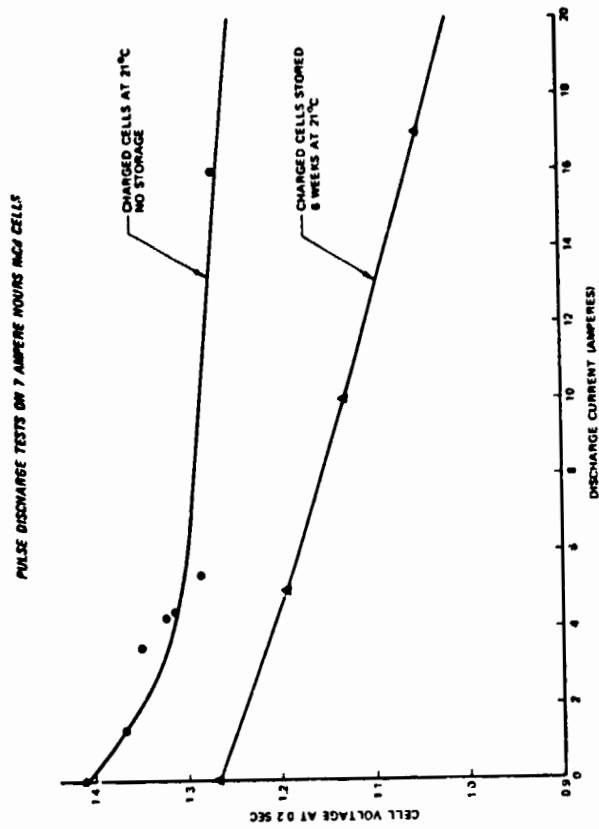


FIGURE 99

dh23

always to fire squibs.

And so, without any particular interpretation, you can see that we have a fairly -- a fair spread in voltage, but in many cases, this is an adequate spread to do the job without any real problem.

Thank you.

FORD: Questions or discussion?

(No response.)

Thank you, Sid.

Okay, at this time, Jim Dunlop from Comsat would like to discuss Intelsat IV storage tests. Jim?

DUNLOP: Thank you, Floyd.

What I'm going to discuss this morning is the current results that we have on our storage test program for the Intelsat IV test that we have running on a real time basis at the Comsat Laboratory.

Now, we have presented a paper this year at the power resources conference that will be out shortly, I imagine, which does cover the work fairly well up to early in the year. The data that I'm going to present today is some data that we obtained since the power sources conference, and it's just sort of an update on the work that we've been doing.

By way of brief review, the test was started back in 1969. It is a real time test. It does have two different storage modes. One storage mode, the cells are continuously triple charged at around a C over 36 rate, the other storage mode, the cells are left on open circuit, charged and recharged every 30 days, C over 18 rate for 24 or 48 hours. I really forget which one right now.

We have removed cells from this test at the rate of about one per year where we do this complete electrochemical and chemical analysis to try and determine what parameters are changing. So that -- now I'd like to get to the test data that I want to present to date.

We have listed here in this table the cells on trickle charge and the cells on open circuit charge storage. The cells that are on trickle charge -- this column repre-

dh24

sents the end of charge voltage. That's the end of charge voltage when the cells are charged at a C over 15 rate, and you're putting in 10 percent more ampere hours than you take out. And you're putting it in at a C over 15 rate.

So, for the cells that are on trickle charge, the end of charge voltage average is about 1.425. This is at 20 degrees Centigrade. The end of discharge voltage, that's at the 23rd cycle of the eclipse season, which is a 72 minute discharge time, and the depth of discharge is 60 percent of the rated capacity. You're getting an average voltage of 1.153 volts. It's fairly low. This is eclipse season number five. This means the cell's been in test now for over three years on a real time basis.

By comparison, if you look at the open circuit storage data, you see that -- well here's one cell that's really pulling out, and I'll show you the IV curve on that in a minute -- the voltage is very high on this particular cell. The same charge, the C over 15 charge rate with the 10 percent over -- C over 15 charge rate.

The average voltage for the cells which are stored open-circuit is higher both on charge and both on discharge. The average voltage here is on charge, 1.45 volts compared to 1.425 volts, roughly 20 milvolts higher.

The average voltage at the end of discharge on Cycle 24 -- which is very similar to Cycle 20 -- is considerably higher. It's almost 1.2 volts. There's a very significant result here. We don't have -- we're not trying to explain it by any physical properties at this point in time; we're just pointing out a result. I don't know if anybody else has ever seen this result, so I think this is relevant. There distinctly is a difference in cell behavior as a result of storage mode, and it isn't one of the parameters that I noticed in that table that was presented in the last slide. But it will affect your performance over long term periods.

And if you have, for example, a voltage limit imposed on your satellite, then you're definitely going to have some problems with this trickle-charged storage mode.

At the same time, you have voltage limits on your charging mode; you're going to have some problems, depending on which storage mode you pick.

(Slide 100.)

dh25

This particular slide shows the voltage characteristics as a function of charging for one eclipse day, and the particular cell that I've chosen to show here is that one that was stored open-circuit, and exhibited this very high voltage characteristic. This is a cell that's pulling out.

Now, this particular cell is pulling out now, after roughly 3 and a half to 4 years real time testing. You'll notice this is the C over 12 charge rate where you see the voltage coming up and as you go into the -- as you approach the fully charged condition, this voltage rapidly rises to -- would keep on going, probably up to over 1.6 volts or so if we didn't terminate it.

At this point, we're switching back from the C over 12 rate to the C over 36 rate, which is our trickle charge rate, and then we continue that rate for the remaining charge portion or semi charge portion for that day.

During this period of time, you see the voltage go back -- drops back down initially, and then rises up and goes over 1.5 volts even at this very, very low rate. This cell is approaching a condition where it is becoming negative limited on charge, based on the voltage characteristics that we're looking at here, and that it's approaching a condition in which there's no charge wait that you can use that you aren't approaching a problem.

Now the dotted lines on this curve show the average voltage behavior for the rest of the cells. It turns out we do have another cell that is beginning to pull out also.

Next slide, please.

(Slide 101.)

We were going to analyze that particular cell, and we pulled it out of the pack, and when we do an analysis, what we normally do first is a complete charge and then discharge before we tear it apart -- open it up and tear it apart. And it turned out that when we did the complete discharge, -- this is the first discharge. You notice the typical dropoff in voltage and this tail-end thing here, which is sometimes observed -- we always observe it after cells have been stored open-circuit for a long period of time.

This cell had 25 ampere-hours of capacity. This

INTERSAT IV Ni-Cd
ECLIPSE SEASON NO.5

TRICKLE STORAGE		OPEN-CIRCUITED CHARGE STORAGE			
CELL S/N	CYCLE 43 EOD V	CYCLE 23 EOD V	CELL S/N	CYCLE 44 EOD V	CYCLE 24 EOD V
083-06	1.413	1.151	051-06	1.543	1.217
109-06	1.431	1.173	096-08	1.438	1.192
122-06		1.179	152-06	1.458	1.208
124-06	1.437	1.172	153-06	1.445	1.211
128-06	1.425	1.161	076-08	1.423	1.188
*002-01	1.417	1.083	097-08	1.431	1.187
AVERAGE VOLTAGE	1.425	1.153	*003-01	1.416	1.181
				1.450	1.196

* GAUGE CELL

FIGURE 101

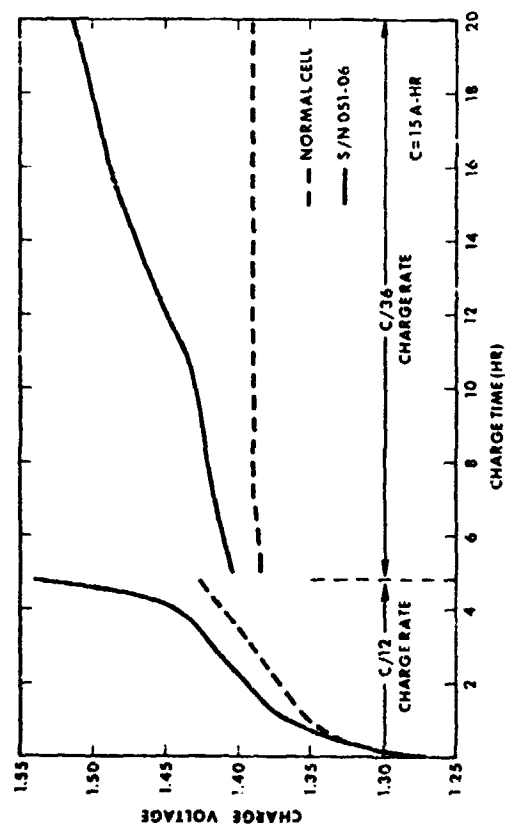


FIGURE 100

dh26

cell is rated as a 15 ampere-hour cell. We went back and we looked at the data that we took when we received this cell from the battery manufacturer back in 1969. It turned out that this particular cell, which is the first one to really pull out in our test program had the highest measured capacity on day one and should have been rejected if there had been a reject criteria for too much capacity. And that's an interesting point. This cell had too much capacity on day one.

It had 23 ampere-hours of measurable capacity on day one when we received it. That's really day one after 30 cycles of testing and then a complete discharge -- to zero volts. Where the normal value for these cells was closer to 21.

This variable is probably a variable that's inherent in -- at least at that point, inherent in at least all battery manufactured chemical impregnation processes, which means that there's going to be some variation in the amount of active material, or the amount of active material that's usable on day one in the cell. And it does mean that the battery's users probably have to set limits both for minimum capacity and maximum capacity, and it's an argument for matching capacities themselves.

That's it.

FORD: No need to ask; the hands are up.

MAURER: Maurer, Bell Labs. On the pack formation data, would this cell stand out as having a high positive capacity?

DUNLOP: I don't understand the question.

MAURER: The manufacturer's tests of this particular cell -- did it show high capacity in pack formation?

DUNLOP: Well in pack formation -- I don't know the answer. The data that we get on the cells, which is the data that they send -- same data that they send to Hughes, just shows the testing that the battery manufacturer's required to do, and that generally is not a complete discharge -- there's no complete discharge to zero volts.

MAURER: Well, the obvious thing here is that this set of positives would match with a normal set of negatives, and so you ran out of negatives sooner.

dh27

DUNLOP: That's right. That's the point.

MAURER: And could you also put this on an activation energy slope and pick out when the next cell is going to fail, from that kind of data?

DUNLOP: Yes, well, basically that's what we've done in the program, and in the program -- that's another approach, by the way, to this business of predicting how good a cell is, is to analyze a sample or a number of samples of your cells, or to take a sampling of data on day one, and then use it to predict how long the cell's going to last, based on the known degradation mechanisms.

Now, in this particular cell, the positive capacity increased approximately 2 ampere-hours in just five eclipsed seasons. That's not unusual. We see the positive capacity growing in all of the cells about a half an amp to an ampere hour per year with either storage mode.

And I've talked to Dr. Maurer before about this. I don't exactly know whether this is an electrochemical corrosion process or a better utilization of the active material as the electrode tends to expand with time. I suppose it may be a combination of both, but suffice to say we don't really see with the nickel electrodes a loss in capacity to zero volts. We see a gain in capacity, and as Dr. Maurer once said to me, "What you really need to do with the nickel-cad cell, if you're trying to design it for 7 to 10 years, you'd better design the negative to work against the positive." And that's the point he's getting at right now.

SEIGER: Seiger of Heliotek. You're right up my question. Can you tell us something about the negatives in these cells? Could you tell us what the design capacity of the negative was, can you tell us what -- can you also tell us the ratio between the increases of capacity of the positive to the increase of capacity in the negative electrode?

DUNLOP: Yes, I can tell you that; the answer to all those questions. As a matter of fact, all the answers to all those questions are really published, but to briefly summarize, this has, if you do a chemical analysis on the negatives, and you find 45, 46 ampere-hours that's the total capacity, theoretical capacity; it's determined on the chemical analysis.

Now the utilization of these electrodes is about 70 percent, even after four or five years of operation. Now

dh28

particularly, and you can measure this amount of capacity in the cell before you take it apart when you trickle charge. Don't let me confuse the issue at the moment. But the utilization is roughly 70 percent, and that means that you have roughly 34 ampere-hours to use, 34 usable ampere-hours in your cadmium electrode.

Now of those 34, you have to use up 21 or 22 just to match the nickel. This leaves you something like an additional 10 or 11, 12 ampere hours remaining. There's a range here. Now what they've done basically in these cells is, put half of it below and half of it above. It means roughly you've got 6 ampere hours precharge usable, and 6 ampere hours overcharge protection before you start seeing the voltage climb.

If you start at day one, and this is based on our analysis of day one. If you go now to a look at the mechanisms which are eating away at your overcharge protection, the two key ones are the increase in the positive capacity and the variation that we talked about here. And the other one is the oxidation of the separator as a result of the carbonate buildup, related to the carbonate buildup.

And those two effects mean that you're diminishing your overcharge protection something like one to one and a half ampere hours per year. It's fairly easy to predict, then, how many years the cell's going to last, and based on -- but with the variation that's in there, you get some kind of a range which is a couple of years.

Another thing that's very critical is the temperature, because the oxidation of that nylon is very temperature dependent. So if you just change the temperature 20 degrees Centigrade, for example, you extend your lifetime for a couple of years. So there are some things of that nature.

HOLLECK: Holleck, Tyco. I want to make a comment with regard to the difference in the discharge voltages after the different charging modes, and I think it might probably that you charge the cell which stood on open circuit at a higher rate, and therefore, you're working at a higher state of charge than with the low rate, trickle charge.

DUNLOP: Let me back off. During the cycling of the cells, they're charged exactly the same at exactly the same rate. The rates are exactly the same here. The variation is the storage mode. In other words, what I'm really saying here is, when I say that's a C/15 rate, that's a C/15 rate

dh29

based on the rated ampere-hour capacity of that particular cell.

So all the cells are charged at the same rate, and if you notice that charge cycle, there's no question that those cells are getting fully charged, because you're charging, with the 10 percent overcharge before you go to trickle charge and then for the remainder of the day, you're putting in a substantial amount of overcharge at a C/36 rate. So the cells are really being overcharged quite a bit on every eclipsed day, and the cycles for both open -- there's no difference during eclipse cycling for those two cells.

HOLLECK: Yes, but I think you noticed this difference in discharge voltage after the storage period. And during the storage --

DUNLOP: No. No, the discharge voltage I'm showing you is on the 23rd eclipsed day. This complete discharge that I showed you, I never do in a normal test, I only do when I get ready to do the analysis. I only did that when I pulled the cell out because I thought I was going to do the analysis. But normally I never do that complete discharge because it's not possible to do that in the satellite.

SEIGER: Seiger, Heliotek. I want to get back to the questions that I was asking and to pass a comment that you have noticed, or you were able to trace back, that you had a lot of capacity in that maverick cell when it was new. And then the capacity decreased later on as you were cycling if the capacity came up again, a corrosion mechanism isn't necessary to explain that. It possibly may.

As I tried to indicate yesterday, you can establish whether there is a corrosion or not a corrosion mechanism by establishing this ratio in the increase of the state of charge of the negative as compared to the increase of capacity. I would like to suggest alternatively that this active material -- pardon me -- I don't know how to really describe it; I don't know whether it's made of nickel hydroxide or the nickel hydroxide -- it doesn't work for a period of time, but as you operate the cell, it starts operating again. And that will give rise to the one to one increase.

DUNLOP: Okay. And the one additional point that I would like to add, since you are on it, is that when we do trickle charge these cells, then we can measure the amount of precharge that we expect to get in there. We can discharge the cells down, continue the discharge in the reversal, and measure the 6 to 8 ampere hours.

dh30

Now, with time, we see that precharge growing. Now the problem is that the precharge is growing for X number of reasons. One is the one you're talking about. It's a little difficult to tell whether it's a one to one ratio now, because it's also growing because of the carbonate buildup. So that's number two.

So you have these various things. Now we have these plots in Atlantic City, we plotted those slopes. Secondly we have the random variation in the amount of precharge that's in there to begin with, which is simply like one or two ampere-hours. So you've got a couple problems here. But you definitely see the thing growing. The only problem is how to separate out which effect is causing it to grow.

But the third problem, which is even more interesting is that you can't measure any usable precharge in a cell which is left on open circuit. And I don't know why; I think it's related to this electrolyte distribution problem again. What we run into is, we get into this approach a negative limited cell on discharge, open circuited, so you immediately think well, you've killed the negative electrode.

So we take the negative electrode out, we put it in a flooded electrolyte, and we measure 70 percent utilization again. So we don't really know what's causing the apparent loss in capacity on the negative electrode when it's in the cell except to assume that maybe it's a problem with the electrolyte distribution in regard to the cadmium electrode.

You don't see this when you continuously trickle charge, and this is a mode where you have your maximum amount of electrolyte, and you're continuously charging and discharging the electrode, as Dr. Mauer talked about. Nastier. So, that's another point.

STEINHAUER: Steinhauer, Hughes. Jim, this open circuit stand, I believe, was charged, then?

DUNLOP: The open circuit is charged.

STEINHAUER: Was there any periodic recharging in this?

DUNLOP: Yes, there's a periodic recharge every 30 days.

STEINHAUER: At the C/15 rate.

dh31

DUNLOP: At the C/18 rate.

STEINHAUER: 18? Okay.

DUNLOP: Just like the satellite. For 24 hours.

STEINHAUER: You have terminated your open circuit discharge test, I believe?

DUNLOP: We don't do that any more.

STEINHAUER: Okay.

CHARLIP: Steve Charlip, Gulton. Jim, you stated that the oxidation of the separator diminishes over charge protection from 1 to 1.5 ampere hours per year, and this is for a 15 ampere hour cell, I assume this is at about 25 CSO temperature?

DUNLOP: Yes, temperature's 20 degrees Centigrade.

CHARLIP: What would the rate of oxidation be, say, if you would increase the temperature to 30 degrees C, if you operate a cell at that kind of temperature?

DUNLOP: 15 kilocalories per mole is the slope.

(Laughter.)

CHARLIP: I meant did you have any experience with it?

DUNLOP: Yes. I'm taking the slope right from Dr. Maurer's points. 15 kilocalories per mole is the activation energy for the oxidation, which is the rate-controlling step.

BARNHART: Barnhart, Johns Hopkins Applied Physics Lab. The fact that you had a cell which ran high in the beginning brings to mind the fact that we have trouble with manufacturers trying to spec, on both high and low sides. Are the manufacturers going to come around to accepting this kind of spec, now?

DUNLOP: Well, I don't know whether it's a manufacturer problem or a user problem. The user can always reject the cells and match them.

BARNHART: Well, we have trouble with the manufac-

dh32

turers accepting that technique. They won't let you reject them. You can't write the spec with those.

(Inaudible remark. Laughter.)

HALPERT: Halpert, Goddard. We alleviated some of this problem by doing plate weight screening, which is in our NASA battery spec, our model spec. And I think in addition that it's nice to be able to do plate weight screening because you get an average, but we still have to know what the capacity of the plates are before you put them in the cells, so. in that way, by getting the actual values of the individual plates, then you can scale up to the cell size, and then do your plate weight screening then, and I think we'll get a lot more uniform plate stack. Uniform capacity plate stack; positive-negative.

FORD: I have a question here.

UCHIYAMA: Uchiyama, JPL. Jim, in one of your slides, you had an asterisk cell, which was gauged, I believe. Would you care to say anything about that particular cell, and the data you might have?

DUNLOP: We don't like the data we get on gauged cells. And the reason I say that is. There are two problems with that particular gauged cell. One is it has dual feed-throughs. I don't see why that shouldn't make any difference. Supposedly, it's exactly the same cell. I don't know what causes the gauge cells to behave differently, but those voltages are lower in both sets, both in the open circuit and the trickle charge. And we just don't know that the gauge cell represents a good comparison.

I don't know whether it has to do with the excess volume or what is the difference, but we've never had a real big success ourselves with getting good comparison between gauge cells or third electrodes, and I don't know what's causing the problem, but something's causing the problem.

SCOTT: Scott, TRW. Were the gauges made of brass? That is, were there brass fittings in contact with the cell environment?

DUNLOP: No.

SCOTT: All stainless steel? Because there are rumors to the effect that brass parts can do something -- I don't know what. I just want to clarify that point. The

dh33

other comment I have is that I think some of the discussion on high capacity cells might be a little misleading. I am for uniform capacity as much as anyone else. However, if you are obliged to say, put a one-high capacity cell, say, in a battery, the rest of the capacities of which are lower, you do not operate that battery to a depth of discharge which is determined by the high capacity cell. You operate it, determined by some average or some combination of the lower capacity cells.

When that is done, I don't believe that it is critical, exactly what depositive capacity of the high capacity cell is with respect to the precharge excess, or the excess negative, because that cell's only going to discharge as much as the rest of the battery does, and the fact that it has a little extra positive capacity, the negative capacity doesn't know that. And so, that the same excess negative in that cell is going to be just as effective as the excess negative in the other cells.

DUNLOP: You want me to answer the question?

SCOTT: Yes, sure.

DUNLOP: Well the cell here did have -- the interesting correlation here is cycled just like all the other cells. We're not -- we're only taking 9 ampere hours in that particular cell that you looked at. It's the high voltage performance that I showed, the curve before we ever ran a deep discharge. The high voltage performance that you're seeing there is the performance that we observed on the real time test, discharging this particular cell in series with all the other cells. We're not changing anything, and -- for that particular cell.

Now the point really, Dr. Scott, is not so much the depth of discharge. The point really is that if you have the same negative stack, and the same amount of precharge in your negative stack, which is set by the battery manufacturer, then if you have two more ampere hours of positive capacity, you have two less ampere hours of overcharge protection.

And the overcharge protection, here is what seems to be causing the high voltage phenomena, and there's a direct correlation between the highest cell that we ever measured initially and the first cell that we pulled out in the test, and if I were to sit down and predict which cell would fail first, this is the cell I would have predicted to fail first.

dh34

I'm going to tell when the next cell is going to fail, and it's going to start doing it on the next eclipse season. I have that all predicted.

The only thing I can't do is predict the variation in the 1 to 2 ampere hours of precharge that they initially put in there.

SCOTT: But are you saying that the high positive capacity causes the insufficient excess uncharged negative. It gives you overcharge protection.

DUNLOP: Well it reduces the amount of overcharge.

SCOTT: In what way?

DUNLOP: Well, if you have --

SCOTT: In other words, if you -- if the cell is designed, and the process is adjusted properly in the beginning, presumably that will be compensated for.

DUNLOP: No. No way.

SCOTT: Well, there is a way.

(Laughter.)

FORD: Okay.

BENE: Jim Bene, NASA-Langley. On that cell that pulled out, was there any attempt to measure the precharge in the cell electrically, and two, was there any attempt to determine the oxygen-recombination capability?

DUNLOP: Not yet, what we generally do, not yet. And the reason I say this is because the cell hasn't blown up yet, and we decided to bring it back into the test, and the reason for that is I think we're going to run it and see when it blows up. Now, what we have done on some cells is actually, there are two days to determine when you start getting hydrogen evolution and what your overcharge -- what we generally do on these cells that we have on open circuit storage, since we don't get any good measurements when we discharge them down, we run into a negative limiting condition. What we generally do is we turn around and charge them back up and then vent the cell when we have the cell fully charged. Trap the gas, do a gas partition measure, measure the quantity of gas, and look for, and continually remove

dh35

what gas; what we're removing initially is oxygen, until we get a substantial amount of hydrogen, also record the voltage.

Now, what happens is that you really don't start generating a substantial amount of hydrogen until you really get up over 1.6 volts in this particular test, and you find you then have a quantitative measurement of how many oxygen removed, and you relate that to how many ampere-hours of overcharge protection you have.

Now in this particular cell, we haven't done it yet, because I don't know whether to blow it up; I'm kind of curious as to whether to blow it up or whether to analyze it.

MAURER: Maurer, Bell Labs. Have you noticed any pattern in the open circuit voltage during after a storage period of cells on open circuit stand. Did the voltage of this cell act differently on open circuit than the other cells?

DUNLOP: During the stand time?

Mar' ' Earl; do you know? Do you remember?

EARL: If they're compared to the cells on trickle charge, then the voltage is lower than the cells stored on open circuit. I don't know about the comparison.

MAURER: I mean among the cells on the open circuit storage mode, would it give you a presignal that this was occurring?

DUNLOP: I don't think it really does until it starts to pull out. See, what happens when it does start to pull -- well, you can see it -- you know, you go back two eclipse seasons before, and you saw it begin to pull out, you see it begin to pull out, and then each season just gets worse. Each time you go into the eclipse season, you just see the cell beginning to get worse, and it starts pulling out from the others, on charge. That's true.

But during the first portion of the charge, it's right in there, and it's toward the end of the charge that it always starts pulling out, and it really takes them -- to get to this point, we knew this was coming -- and we know it's coming on other cells, because we see the trend developing. It takes a year; you have to be very patient with this program.

(Laughter.)

dh36

RUBIN: Rubin, Tyco. I'd like to speak to Will Scott's point about the capacity of problems. I think if we look at two given cells with the same negative capacity, if one cell has a larger positive capacity, then the amount of overcharge protection available to that cell has to be reduced by the difference.

I think, Will, your point is correct if one doesn't work at the top of charge. If one never overcharged the cell, then one need not be concerned about the overcharge protection. However, if one is always topping his cell off, then you have to be concerned about the overcharge protection, and I think Jim's data is important at that point.

BETZ: Betz, Fairchild. Just a general comment or two on cell procurements. We do buy cells to capacities with a tolerance plus and minus, and the manufacturer does keep the higher capacity cells as well as the lower ones, and the Fairchild spec also specs excess uncharged capacity in the negative electrode for overcharge protection, rather than precharge setting, the value on that.

FORD: The next presentation, I plan to present it, is going to contradict or confirm what Jim just said. I'm not sure which.

(Laughter.)

FORD: But it does deal with the same area, and some of the things -- your questions you're asking -- I have data to discuss, so okay, it is five after eleven, I'd like to say let's take the coffee break, let's come back and pick up the subject.

(Recess.)

dh37

FORD: At this time, I would like to present some results of a test on the OAO-type cell, it's a Gulton 20-ampere hour cell. It's made by Saft, in France, using nylon separator Pellon 2505.

The reason for conducting this test was brought about a couple of years ago when we got suspicious from observing battery performance in a spacecraft during ground testing. We got suspicious that there was things that were going on and the change of characteristics in that battery that were not happening on our cycle test, or not happening to cells that were stored.

As a result of this, we decided to set up a test to look at the effects of what I refer to in my charts as an integration. Now, it's your guess as good as mine as to what they do to a battery in spacecraft in integration periods. I can tell you this: They do keep it within certain constraints as defined by the charger, and the environment, so they don't abuse it intentionally, although sometimes there are mishaps that do occur.

To set up the integration tests was one of the most difficult ones, because we had to come up with a sequence -- a random sequence. We picked about five different things you could do to the battery. But I'd say about 40 percent of this time, the battery was left open-circuit, and usually left open-circuit after being trickle charged all day, or maybe being cycled a couple of times during the day, but the weekends, the battery was always left open circuit. It was only activated or used in a charged condition or discharged condition during the eight hour workday shift.

To compare with this, we chose the second test, a trickle charge. And that was pretty straight forward, C/40 trickle charge continuously, day in and day out, 24 hours a day.

The third test was to look at the cells and use this kind of as a control group, was the cells would be discharged and shorted. So we had three packs of five cells each, and this was all done at room temperature.

We started off with what we call a "prestorage characterization." This included several series of tests. I won't go into the exact sequence, because we did make a point to keep the sequence the same from prestorage. At six months, we took the cells off of their various modes and ran them through this same sequence. At twelve months, we took

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the cells again and ran them through the same sequence. Each time putting them back in the storage mode they were in, and at the end of eighteen months, we did the same thing. And I just recently completed analyzing the data after eighteen months.

The type of test we do includes a low temperature overcharge test. We did one initially on the prestorage; then at six month intervals, we take the cells out of their respective storage conditions with the exception of the pack that's discharged; we condition that pack at C/20 for 48 hours. And then all three packs go into a chamber, four hour stabilization; and then we do a low temperature or 0 degrees C. overcharge test where, from the stabilization, C/40 trickle, we do a five minute discharge at 6 amp rate on a 20 ampere hour battery, followed by, immediately, a five hour charge at C/20.

I won't go into the history of why we use this particular overcharge test, but it was relevant to all of the previous history on the OAO program, that we had data at 0 degrees C.

Following that, we do three capacity tests. We do another overcharge test, and in the interval between the capacity tests, we do an open circuit stand test. And then the cells go back on storage.

First slide, Tom.

(Slide 102.)

If you'll notice across the top, I've listed the pack number. 215 A is the integration pack, 216 A is the shorted pack, and 217 is the C/40 trickle. On the left hand column, the -- I'll show you the initial conditioning cycle capacity before the cells were put into a pack, and this is times in minutes at C/2. If you want to convert that to capacity, I believe you can divide the number by 6 and you come out with ampere hours.

Showing you the uniformity of the cells, and these cells had been through all the preflight acceptance tests, and cell selection tests. They would, or could have been used in the flight battery that was manufactured for the OEO spacecraft.

You notice that after we assemble the cells in a pack, then we begin to look at the lowest capacity cell, because that is a determining capacity in this type of test.

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Two interesting points is, I show the 6 month, 12 month and 18 month interval. If you see, there is a definite trend with trickle charge that the capacity of this pack to a half a volt, is increasing.

Now, if you'll remember last year in the workshop, we discussed the voltage effect in which I will show you a discharge profile of these two conditions here, and compare them. The interesting thing is that this indicates a large increase in capacity compared with the day one. This also indicates a fairly substantial increase in capacity, but what is significant here I think if you look at the voltage time profile, is that the energy, the watt-hours in these cells, irrespective of the discharge time, is approximately the same.

The pack that showed -- well, I would say the minimum change, but actually, it showed a slight decrease in capacity is the one that was shorted discharge. The pack that showed the -- I would say the intermediate change in capacity was the one that was -- during the integration period. And I'm looking at the data for the 18 months, particularly.

Next slide, Tom.

(Slide 103.)

From the last figure I reference, the two capacity discharges on the pack that was on the trickle charge, I show you a comparison of a discharge profile, after 18 months, obtained on the first discharge -- in other words, this pack has been on continuous trickle charge for six months, and this is the 18 month data point. I show after taper charge, recharging the pack up, that we do a subsequent discharge which I called the third capacity -- well, this was actually the second, and then the third capacity cycle, where you see the voltage is up very close to what the cell voltage was when it was new.

However, the significant thing is that this point here, to half a volt, when it was new was back here less than 150 minutes -- about 144 minutes. So there has been about a 1 ampere hour increase in that cell's capacity.

The point I alluded to earlier is the fact that if you look at the total energy storage in the cell under these two conditions, it's going to come out to be approximately the same.

dh40

(Slide 104.)

The other test I mentioned is an open circuit stand test. Let's look at the prestorage test, because that in itself is a point for considerable discussion. We have a requirement that all cells meet a minimum of 115 on this open circuit stand. This consists essentially of a C/2 discharge to each cell at one volt. You have on the cell for 16 hours, take the resistors off at the end of 16 hours and look at the 24 hour open circuit recovery voltage. And at the end of 24 hours, that's when these numbers are taken.

The interesting thing is the prestorage open circuit test was run after the initial conditioning cycle at these cells at Crane. In other words, they had been in discharge and shortage for some period. And I'd just like to make a comment there is that we have observed that after cells have been discharged and shorted for a long period, if you run this without two or three exercise-type capacity checks, the open circuit stand voltage on this test may give you an erroneous result. We don't recommend doing it after the first capacity cycle.

But the interesting thing is looking at the 6, 12, and 18 months. Now, there was a difference in the sequence here that I guess I wasn't aware of until I really analyzed the data. The 6, 12, and 18 month intervals, the open circuit stand was conducted after the second capacity cycle. So I ask you to compare the 18 months line across, and you see that the cells that have been shorted still have a what we consider healthy open circuit recovery voltage. The cells that have been trickle charged show some degradation relative to the other pack, as with the cells on integration.

(Slide 105.)

The other thing that we look at and are very conscious of for many reasons is, what happens to the overcharge voltage at 0 degrees C. And I guess of all the data that we've got, this to me is the most impressive.

Again, using the same profile to compare the data, showing you the overcharge data -- now, this is the end of the five hour period for the prestorage data, and it's in the five hours for all the other data points with the exception of the data listed on the integration pack which I have noted that, in the six month interval, we never went the five hour period; we had a like 2 hours 15 minutes, 2 hours 30 minutes; in all cases, the overcharge test had to be terminated either

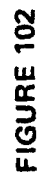
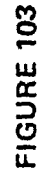


FIGURE 105

FIGURE 104

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due to excessive voltage, or, in the last two of the twelve and eighteen month periods, the high pressure in the cell. High pressure meaning that the pressure exceeded 75 PSIG which is a factor of three above what the cells would normally do.

The interesting thing is that the integration battery, the fact -- is similar to the integration period, has shown a profound increase in overcharge characteristics. But what I did -- incidentally, one other point. The reason I can say the first and second tests, the first test I mentioned, as I mentioned previously, is run immediately at the storage period. No capacity discharge would go right off from that storage period right into the overcharge test.

Then, after two capacity cycles of recharge, we go back into the overcharge test, we inherently see a slight decrease in overcharge voltages from the first to the second test. So what I'm saying is that the overcharge voltage, in the sense of improving with the couple of conditioning cycles.

Now the question was asked to me last week, "Well, do you think from that, could you work the cells to the condition that the integration pack would get back like the other two?" And the answer is no. We have tried this previously; we didn't have the controlled test conditions, but we did have cells exhibiting this type of voltage, and we found there was no way to get them back down to like new conditions.

(Slide 106.)

What I've done in the next three slides is show you the five-hour period at the overcharge test, comparing the prestorage data with the 18 month second test period. Here is the discharge and shorted, and as you see, very little, if anything, I'd say that probably could be accounted for in the variation in the test parameters themselves, like the absolute control of temperature, and so forth.

Keep this one in mind as we go through the next two.

(Slide 107.)

Here is a trickle charge pack showing that the peak voltage has increased, but not the plateau. This to me signifies the onset of a degradation that gets worse and worse with time. In fact, we had observed this previously in cycling; that the first thing you see change in the overcharge test is this peaking effect here. It starts increasing, and it may

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go up by a factor of two, while the end of charge, or the plateau voltage that I referred to may show very little change, if any.

(Slide 108.)

This is the pack that went through integration. And I'm showing you the highest of the cell voltage, but as you saw previously, all cells in that after 18 months was a better than 155. The test was terminated at that period, because the cell pressure in one cell got up to better than 75 PSIG.

The status of this test is this point; we have pulled one cell from each group. The eighteen month period ended, incidentally, about two weeks ago. We pulled one cell from each group, it would go through a complete chemical analysis, and we're also going through a plate capacity measurement, to compare with the new plate data that we have on this particular lot of cells.

Thank you.

(Applause.)

SEIGER: Have you analyzed the gas pressures yet?

FORD: No, I don't have to. I can look at the pressure at the end of discharge and tell you it's not oxygen.

DUNLOP: Jim Dunlop, Comsat. The trend that you're indicating is, and I'm not sure I'd disagree with you Floyd, but certainly it's nice to see somebody else to come up with some data that I think generally agrees.

Three or four points seem interesting. One is that with your trickle charge, you do indicate that with a trickle charge mode, there is a loss in voltage that's recoverable by a reconditioning. One of the things that we observed is that if you can recover that voltage loss by reconditioning, but the recovered voltage that you got doesn't last very long. The more you cycle the cell, the quicker you go right back down and you lose the effect of the reconditioning.

Two, it looked like you had a problem with the cells that were left on open-circuit charge, and periodically cycled in some fashion. The problem seemed to be with regard to the negative electrode in terms of charging. There didn't seem to be as much -- it seemed to be more of a problem. You

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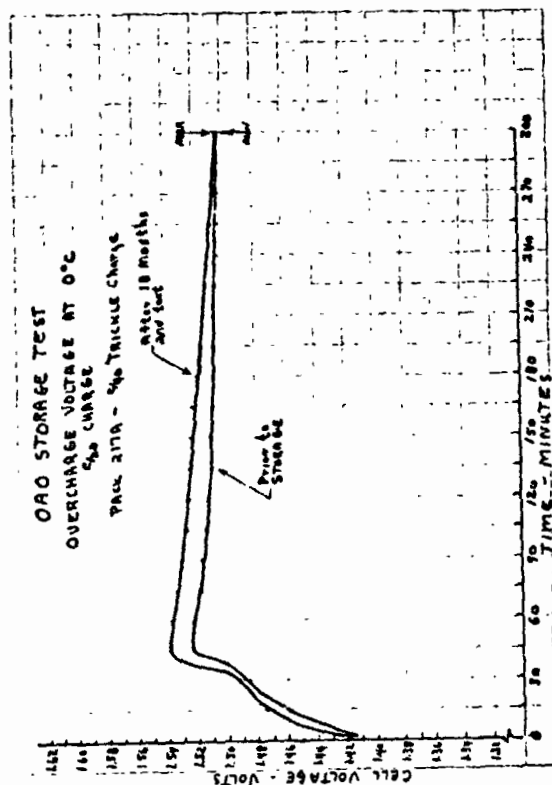


FIGURE 107

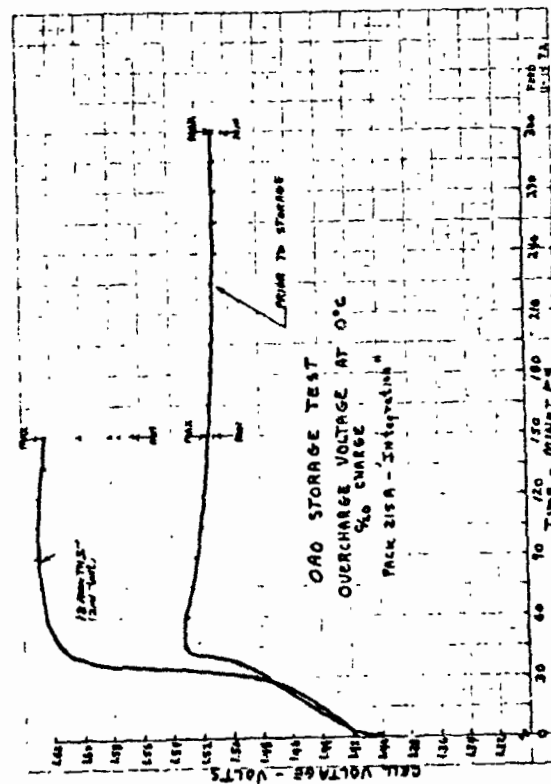


FIGURE 108

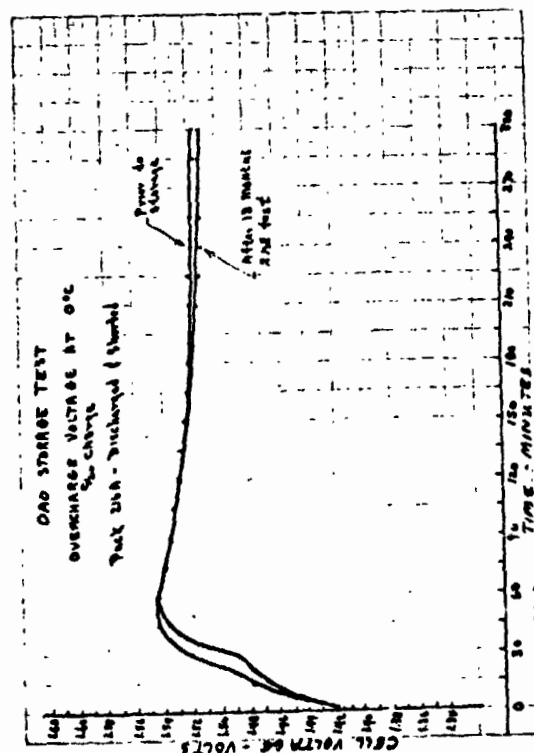


FIGURE 106

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seem to be becoming negative limited on that electrode. It particularly showed up in your low-temperature data at the end there.

I'm not sure -- it'd be interesting if you run some flooded measurements on those plates to determine whether or not the apparent loss in capacity that you're seeing there is due to actual passivation of that cadmium in some fashion, or whether it's due to some problem with regard to the electrolyte redistribution, again.

FORD: Okay, I'm not -- are you looking for an answer, or just -- I have a comment; I'm not sure whether I'm supposed to answer that or not.

DUNLOP: I guess the one thing I would like to have you say is, what's your conclusion from all this? I don't know that you really made a conclusion.

FORD: Well, I know how to kill a battery for space applications. Give it to the integration crew and let them use it for 6 to 12 months. And in that capacity, we have a real basic problem on our hands, as people that supply batteries to spacecraft and projects. Because it is a standard policy that all flag units go into the spacecraft and be integrated and go through all the environmental testing. What we have is a perishable item. We've got to put that point to the project people and make them aware of this.

I'm not so sure, and I can't back this up, it's conjecture on my part, that every day that battery sits in the spacecraft in an integration mode, is equivalent to one or maybe more days in orbit, in use. And what I'm saying is, every day you have in that spacecraft, you're taking away a day of use in orbit. That shakes a project manager.

DUNLOP: Can I quote you on that?

FORD: You can quote me on that. Conjecture on my part.

(Laughter.)

KIPP: Ed Kipp, Gulton. I think I can substantiate some of Floyd's feelings on integration cells and batteries. In four years of experience at GE on the NIMBUS program, the worst batteries we ever had were batteries that were used on the integration and debug spacecrafts.

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The way they were used, they were let stand open-circuit for periods of time, they were overcharged for certain periods of time, they were cycled for certain periods of time; everything on a very infrequent, unscheduled basis, and those turned out to be in the long run the worst batteries we ever saw in the whole spacecraft, and that was in four or five years of experience.

FORD: Okay, well, in light of that, I don't think -- we're going to have to make some compromises. They have to put the battery into spacecraft before launch. That's obvious. Otherwise, we wouldn't be in business.

So what we're going to have to do is come up with a unified approach from the battery users, manufacturers, on what we feel like is best for the battery. That's not saying we're going to get it, if we go to the project people.

But I would like to throw something out for your consideration. We've already implemented this on one program, and we'll probably see it implemented on most programs. When we started looking at this, we said "Well, how do you normally turn the spacecraft on in the morning? You know, the crew comes in by 9 o'clock, they've had their coffee, they've gone to work." They typically turn a spacecraft on -- and the procedure says "charge the batteries." Even though the battery was only open circuit, 12 or 14 hours.

Well, think about this for a minute. A battery has been charged the previous day; it's fully charged. Self-discharge is not a factor here even in a 24 hour period. You've got to talk about two or three weeks at these temperatures before you have to worry about self-discharge. But when you turn a spacecraft off in the evening, you've had some equilibrium point reached; the battery -- the pressure is stabilizing itself, that pressure goes away in about 3 or 4 hours on open circuit.

The next morning, you come in and hit that battery with even a C/10 rate, or it could be higher; it could be as high as C/2, depending on the spacecraft system. There is no oxygen in the cell, and I suspect that right there, you're doing -- you're having a very detrimental effect on the negative electrode. You charge the cell; there is not the normal process of oxygen evolution, recombination, the closed system that I referred to, that you would get when you discharge then come back up in state of charge, and overcharge the cell.

From this thinking, and we have nothing to -- well, there is a little something in this integration period. We

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tried this on these cells, where we had pressure, and we noticed a profound difference in the charge voltage, and in the pressure characteristics during the day, depending on whether we discharged the battery first in the morning, or when we just came in and started to charge it.

As a result of this, we are now recommending a standing procedure to energize the spacecraft, energize it, and let the battery discharge for 15 or 20 minutes, then initiate the charging. That's one way out. I don't think it'll solve all the problems we see here, but it's a kind of short-circuiting some of the problems I think we're getting ourselves into.

BRIGGS: Briggs, Philco-Ford. I'm curious about how many programs we've flown that have flown fresh batteries that have been put in at spacecraft integration, and how many programs we've used the flight batteries for the spacecraft integration.

Do you have any knowledge of what percentage of the programs --? I know that there is --

FORD: I can name -- 1, 2 -- I know the OAO 2, which is coming up in four years, and I guess it's been one of the most successful batteries we've had in a while. December the 7th will be four years. That battery was installed about two weeks prior to launch. Not by choice on the project manager's part, but we just weren't satisfied with what we had. So we had a new battery made.

And we went through the same sequence on the last OAO -- the one that was launched this -- September. A fresh battery was installed at the Cape. The precedence had been set. I remember another program which really is a program that prompted us to really get involved and look at this, was on SAS-A. They were sitting on the pad in San Marco, they ran an overcharge test, again at room temperature, or whatever it was, it wasn't cold. The cell voltages just went out of limit. All the cell voltages went beyond specifications. They replaced a battery there, because they had a battery -- same lot, everything had been in storage, and the discharge -- I believe it was discharged and shorted; I'm not positive of this. They put that battery in there, and they flew with it.

And that has been a very successful mission. So the precedent's been set. We have a job to convince the project manager that this is what we've got to do. And I think two or three years from now, I hope we can stand up here and

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say we've accomplished this.

UCHIYAMA: Uchiyama, JPL. I'd like to comment on some of the things I've heard mentioned. Being a user and a supplier of batteries, I can well understand his frustrations in terms of his integration tests, and how he interfaces with the project people and systems-type people.

I think it's easy to complain to them, the fact that when they test batteries they are subjected to many things which the battery people would prefer not to have the integration people subject the batteries to. But at the same time, I can see certain things that the battery people can do and should recognize, when the battery goes onto the spacecraft or goes into the hands of the actual user, and that is to recognize the fact that most of our tests, and most of the tests we've heard about here today have assumed that when the battery is under load, it is an ideal situation. That is, just a plain, ordinary resistive load. And this is not the situation when you put it on the spacecraft.

Very frequently, and quite often, the immediate thing downstream from the battery is not a simple resistive load. It may have pulses; it may have its own shape, and so forth, and until we find out what that shape of that pattern is, the battery people are really not going to be able to supply real good data and to correlate the idealized situation that we've run our tests under.

So I think, without meaning to criticize anyone here, I think the battery people should recognize that there is this interface problem. And this is perhaps the reason why you might say that when you subject the battery to integration-type tests, that perhaps it takes a day or two life out of the actual life of the battery, I think that's very true.

But at the same time, let's recognize the situation, and when we subject our cells and our batteries to tests, to make them a little bit more realistic in terms of the actual load situation.

BETZ: Betz, Fairchild. About two years ago at this workshop, Mr. Bogner of JPL presented Mariner-Mars '71 battery handling procedure, and evaluated the three concepts; put the flight batteries on at the last minute, use them for integration for the entire period, and then the technique they finally adopted, which was, use integration batteries up to a particular point in the test, and then use, put the flight batteries on, for a short period of time, for final

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testing with the spacecraft, shortly before launch.

This I think worked out pretty well in MM '71, and in fact, this is what Fairchild has adopted for ATS-F and G.

STEINHAUER: Steinhauer, Hughes. We generally handle batteries on the spacecraft by assigning a unit engineer who lives with those batteries. In fact, we've almost launched a few unit engineers.

(Laughter.)

But the point is that we do integrate the flight batteries on the spacecraft, but at times where that spacecraft has to be subjected to all levels, particularly high temperature, or something we do not want that battery to see, we do not hesitate to break a thermal interface, or pull those batteries from the spacecraft temporarily, or if it's going to be an extended period, to store them under a controlled environment condition -- off spacecraft.

So I think there's several plans that can be used, but I agree with your point. We must watch these batteries at all times from cell manufacture through launch and after.

MAURER: Maurer, Bell Labs. I agree with your point on the problem of starting to charge a battery that's been standing on open circuit. We have a policy in applying commercial batteries, to telephone systems, we do not allow a condition we call "interrupted overcharge." In which the long-term overcharge is stopped, and the battery not discharged, and then started up again.

This has invariably led to cell venting. And so, when we have a system that has this type of use, for example, we have a battery supporting a semi-conductor memory. The battery is in two parts; one section provides a gate voltage to an IGFET. And the discharge current is in the microamp range. It's too high to use a capacitor, so we use the smallest battery that we can conveniently get in the neighborhood of 100 to 200 milliampere hours capacity, and what we do is put a resistor across the battery during the discharge phase of the battery so that that section is discharged at perhaps a 20 hour rate through the resistor.

And of course, C/500 or something like that through the load. In order to assure ourselves that when the battery is put back on charge, when power returns, that we won't

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have this condition of high voltage and hydrogen burst.

FORD: In reference to a question that Jim asked me that I have yet to address myself to, do you have any idea why this may affect, or what the effects may be on the cadmium electrode?

MAURER: Well, if you look at a potential sweep during charge of a negative electrode, especially at high rates or lower temperatures in a flooded state, you'll get a high voltage section at the beginning of the charge in which you evolve hydrogen, then the electrode settles down and charges normally until it reaches near the end of charge, then it generates hydrogen again. And you want to operate in the section between those two. And this is why we put precharge into cells for our reserve use where they see very low temperatures.

And what I suspect happens is that on long overcharge, or open circuit, you lose the oxygen as you describe, and you're left with the electrode in a peculiar state, similar to what you have at the beginning of a charge, where most of the active surfaces are semi-passivated, so the voltage starts off immediately at the hydrogen level, and then as oxygen comes over, and as the negative charges a little bit, the voltage drops off again. So you get this hydrogen burst, and if you repeat this enough times, you build up high pressure.

YUEN: Joe Yuen, Naval Research Lab. For the record, I'd like to bring this point out: For all of our satellite launches, we always have two types of batteries. One, the flight type, and one would be the test pack.

During the test of the payload, the project manager can use the test pack throughout all tests, and two weeks prior to launch, we install the flight pack. The flight pack will be almost similar to the test pack in every detail.

FORD: Any other discussion?

(No response.)

Okay, the next subject we have is charge retention, testing, measurement of excess negative capacity. Will Scott, TRW.

SCOTT: This is one of those somewhat last minute, less formal presentations, actually. It isn't a presentation,

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it's just some comments, but I hope it'll be a little easier to stand up here, possibly.

We've been talking a little bit about updating and presumably improving on this NASA nickel-cadmium battery specification, and I think everyone is aware that there are a number of things in the original version of the NASA interim spec that was generated a number of years ago, that need improving.

Unfortunately, some of these improvements have been dragging for some time, and as a result, the errors of our ways that were incorporated in that original interim spec have been perpetrated, promulgated, and by this process, as often happens, they sometimes become the law of the land, even though they are not necessarily the best way to do it, or even may contain some obvious defects.

I'd like to address myself to two aspects that I think should receive some additional attention before, hopefully before they become incorporated into any new version of that type of specification.

One is a method of testing for so-called internal shorts, or charge retention. The other is the method of measuring excess negative capacity recharge, and so forth. With regard to the method of measuring charge retention, there are, as most of you know, two somewhat different methods generally in use, one is to short down the cell then introduce a small amount of charge, then open -- let the cell stand on open circuit for say 24 hours, and measure the voltage at the end of that time.

The other method is to short the cell down, then open-circuit the cell, and measure the voltage rise, the voltage at the end of a certain period of time, standing on open circuit. There are various proponents of both of these methods. I don't have any specific new data to solve the question of which is better if either one is better. But I would like to reexamine the real basis for either of these tests, and to ask just what it is that we are really measuring.

I ask this question of individuals now and then, and I get all kinds of answers. And I would -- I presume that the original intent was to detect some kind of internal electronic shorting path between the electrodes. This is what I think we would like to do.

However, I submit that the way these tests are

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generally conducted, it often -- it could happen that the results obtained are more a function of the particular potential behavior of the positive electrode under the test conditions than they are of any shortage condition of the cell.

This kind of remark arises from some various experiences that we have had in the past, in using the first of the two test procedures that I mentioned. Namely, charging the cell, say, at a C/10 rate for five minutes, or ten minutes, and following a short-down, and then watching the -- then measuring the cell voltage after 24 hours.

We've performed this test on many, many cells, and although certainly the very large majority of them seem to fall within certain limits, there are a certain number of other ones which, although they do not fall within the presumed safe limits, seem to perform perfectly well as in all other respects, in terms of cell performance. And I do not like the idea of having to reject cells for a test which I don't have any idea what the real scientific basis is, and the performance in passing and failure criteria are as arbitrary as they are on this particular test, where all the rest of the cell performance parameters are perfectly adequate.

Let me mention specifically some of the strange things that we have seen during this type of testing. I guess the most disturbing is that the -- well, first of all, in order to really see something, most of these strange things happening, you have to monitor the cell voltage continuously throughout the period of time when normally speaking you're supposed to leave the cell sitting open-circuit on the shelf and not be measuring it at all.

If you say, take a suitably specified instrument that doesn't draw any appreciable current from the cell, and monitor the cell voltage continuously, on a certain number of cells, you will see the voltage start to go down slowly or even more rapidly on open circuit, and then it will come back up again. And then it will sometimes go down again, and sometimes come back up again. And this could go on and on and on.

I submit that as long as this kind of thing can happen, that this type of test leaves something to be desired as far as its reliability in detecting internal shorts in the cells.

Also, what we have observed is that when we suspect that there may be something funny, or that there may be a test error, and retest cells that fail the normal criteria for this

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test, almost invariably, the cells will pass the second test, and they will pass all subsequent tests.

I suspect that the results that we obtained on the first test are being influenced by the exact prior history of the cell condition, prior to conducting the test. Specifically, I believe it's possible that, for example, if you happen to conduct the test after the cell has been shorted for quite a long period of time, you can get a completely different pattern of behavior than you would if you short the cell only for say one hour, or don't dead short it at all prior to charging it, giving it the initial boost charge, and then conducting the test.

I guess the point here is that I sort of doubt that we, at least not everyone is controlling all of the variables that can affect the results of this test adequately. So that the test results are likely to give you some misleading values.

So, I just think that if the test is going to be made meaningful at all, the first thing that has to be done is to recognize all the factors which can lead to variable results, and get them under control. The other thing I would recommend is that -- possibly that this test always be performed twice, rather than just once, and make sure that you can reproduce the results the second time in a row.

At least, either that, or to always provide for a retest of cells that fail this test the first time, just to make sure that the previous history is not unduly influencing the result.

The other test I'd like to comment is that for -- that presently exists, at least in several documents that are now being used, and actually imposed upon prime contractors, is the procedure for measurement of excess negative capacity, as it presently exists in the -- for example, in the NASA specification S-761 P-6. Dated March, 1971.

As it came out a year ago at this meeting, I think it has been recognized for some time that that test, as described, does not actually measure all of the, or may not measure all of the precharge that really exists in a cell. It will measure some part of it, and unfortunately this part may be -- can be quite variable, and I don't believe that we understand exactly what variable, what variables affect the amount of measurable, electrochemically measurable precharge that can be obtained during this test.

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I'm concerned mainly for one reason. And that is that if you -- I believe that all the discussions over the past few years have possibly placed a little too much emphasis on the need for precharge without a comprable, balanced recognition of the need for sufficient excess discharge negative.

And if you look at that procedure, you'll see that the only way that procedure gets you to a determination of excess uncharged negative is to subtract two terms from the total excess, the total negative capacity that is determined by that test.

Now, the problem as I see it is that there's some uncertainties in the determination of both of those, of all three of those terms. But if you, even if you could determine the total negative capacity accurately by this test, there are some larger uncertainties, I believe, in the determination of the other two terms, the -- you know, TTN 1 and the TP 3 and the TN 3 terms, so that when you subtract those two from the total negative capacity to get the discharged excess, you could have a large error in that calculation.

Now, if you -- so that, if you have, if you're not very careful in determining the value of both of those two terms that you subtract from the total, you could be in trouble as far as your excess discharged negative is concerned. The trouble that I'm talking about is that you could fool yourself into believing that you have a lot more excess discharged negative than you really have.

This would be the case, for example, if the method that you use to measure precharge did not measure all the precharge. Therefore, you get a smaller number for that term than you should. And when you subtract that from the constant, hopefully, or the reliable value of total negative, you're going to get a larger number for that difference than really exists. So that's going to give you -- could give you a false sense of security as to how much discharged excess negative you have.

Now, specifically, it came out last year, and most people I think are aware of it now, that this electrochemical procedure normally does not measure all of the precharge that's there. You have to go to some combination of electrochemical and chemical methods to really measure it all.

So that if you measure the precharge by that, as it's written up in that procedure only by electrochemical methods, you're going to get a term that is quite a bit smaller

than the actual amount of precharge. If you subtract -- assuming that the real amount of precharge is a lot larger than you measure, presumably, it could be that total term that you should be subtracting from the total negative in order to get the true discharge excess negative.

So, what I think that we should probably be doing is taking another look at that procedure as it is now written, and to decide, for example, whether the value that we really should be plugging into that equation to calculate excess discharge negatives should be the total real precharge. And therefore, whether we really should be using combined electrochemical and chemical methods to determine that term of that equation.

This is my thesis, and I'm throwing it open to discussion.

MAURER: I'd just like to comment on Dr. Scott's results on the open circuit voltage recovery tests, and talk for a moment on some of the things that we've seen, and some of the theories we have of how it operates, for the type where you discharge and short out the cell, and then put it on open-circuit and measure its voltage on open circuit, as opposed to the one where you give it a slight boost of current.

(Slide 109.)

First of all, the positive electrode discharge is a diffusion-limited process where protons are diffusing in and out of the active material. And during a normal discharge, we plot voltage versus time, we get a section (A) where the voltage is independent of time to a first approximation, and then we go over a knee, and I'm talking about a situation where we're discharging the cell across the resistor.

Now, in this region (A), the diffusion-limited current is much higher than the load current requires, so the voltage is controlled by other factors like the electrochemistry of the positive.

As you get below roughly .8 volts, you get into a region (B) where the voltage drops off in an additive, logarithmic, section, and if you plot the log of the voltage, versus time in this section, what you get is a series of -- you can analyze the curve into a series of straight lines whose slope varies in the ratio of 1:9:25, just like you predict from a diffusion process, $2N$ plus 1, squared, factor. So that it's supporting evidence that this is really a diffusion-limited process.

Now, the current coming out of the electrode during

that period of time is independent of the load. So if you put a 1-ohm resistor, or if you put a dead short on the cell, the current coming out will be the same.

And this tail will continue for several days, and with a half ohm or a one-ohm resistor, you can measure appreciably voltages after 24 hours, certainly, in the neighborhood of 10, 20 millivolts, something like that.

(Slide 110)

Now, then, what happens, I believe, during the open circuit recovery is that you have an equivalent circuit, a capacitor, with a resistor in parallel, and that this is driven by a current source which turns out to be that diffusion current in the positive electrode.

So, such a system has already been shorted out by an external load resistor so that the voltage on this capacitor is zero, or close to it. Now we take this resistor off, and begin to charge at that diffusion-limiting current, from the positive active material. And of course this capacitor will charge according to standard electrical laws; it'll be a logarithmic rise like that.

(Slide 111.)

As long as this current is roughly constant, then this voltage will depend on several things. One, the voltage that this source will provide, namely the 1.2 volts of a nickel-cadmium cell, and the other, the size of this resistor. And the smaller this resistor, of course, lower the voltage.

Now, the problem comes in -- an additional problem comes in; is that this source isn't a constant current source, during the time scale of this test, the open-circuit recovery of 24 hours, the voltage of that positive active material is decaying. So, this current source is decaying with time across the fixed system, so what this will then do is drop off again.

Now just how the relative amounts, size, of this current and that resistor will give you a whole series of different curves, we simulated this with small, 100 milliamperes cells in which we deliberately put resistors of various sizes across them to simulate this resistor, and we could get curves that varied from that (1), to of course, something like this (2-3), or something that didn't rise at all (4), and these resistors, for this neighborhood (1-2) was in the neighborhood of 100 K in that ballpark.

So, if -- let's see, the other variable on the pattern is how long you've shorted the cell before you start.

If you short out for 16 hours, you might be operating from this current level (ref. 109), and of course get a very fast rise (curve 5, ref. fig. 111). If you short out from this point out here, (ref. fig. 3, curve 6), like 48 hours, the current source may be very small, and you'll get this kind of response.

Now, there's an additional effect that we've seen that I don't have a solid explanation for. But the voltage does not rise immediately. It goes up like this (ref. fig. 111, curve 7). It's exponential, once it starts. But it has a delay time. This is the open-circuit recovery. And I don't know why that delay occurs; again, cells that have this appear to operate in charge-discharge mode similar to ones that don't have it, so it doesn't appear to be related to some of those kinds of performance parameters, but cells that exhibit this will have all of these features, as well.

Now, another point that Dr. Scott mentioned was that he got a different effect depending on whether -- what the prehistory was, and of course that comes out of this, (fig 1), the current performance on the discharge, on cells that have been let's say aged, many times will have a much different history in this portion (ref. fig 109, region B) that I think can probably be related indirectly to here.

So some of the things that should also be measured on this test I think are the current, and the rate of decay of the current during that discharge, the shorted part of the discharge.

(Slide 112)

And then another factor (fig. 4), which unfortunately has to come in is that if this circuit represents one region (region 1) of the electrode, there's also another region (region 2) of the electrode that you can write in the same way with its own current source, and this one is connected through some kind of resistance ^(R) to this one to form the outside world. And so the resistor on the outside world that you put across this whole circuit now, will be discharging the two sections of the electrode differently; this section (2) through a different kind of resistor.

(Slide 113)

So if you do that, then the discharge voltage profile during the shorting time will have a much higher current than one in which this resistor (fig 112 R), let's say, is zero, all the electrode is uniform, that one might come down like this (fig. 113, curve 2). But of course, you'd rather have this kind of electrode (fig. 112, R equals 0) or cell with this kind of electrode; you don't want this kind of internal resistance in the cell.

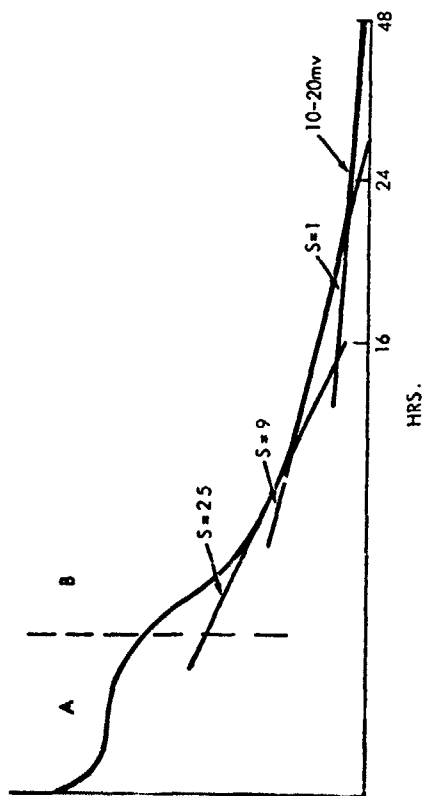


FIGURE 109

56A

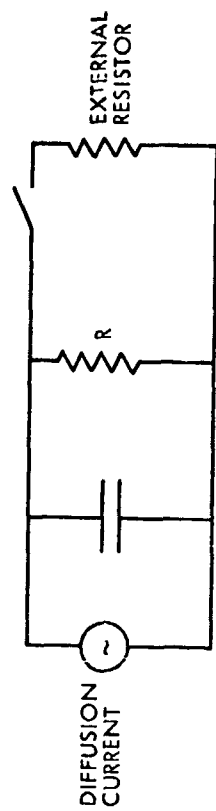


FIGURE 110

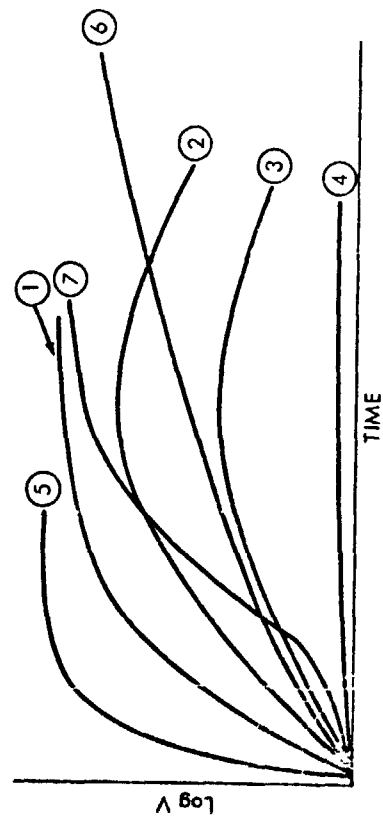


FIGURE 111

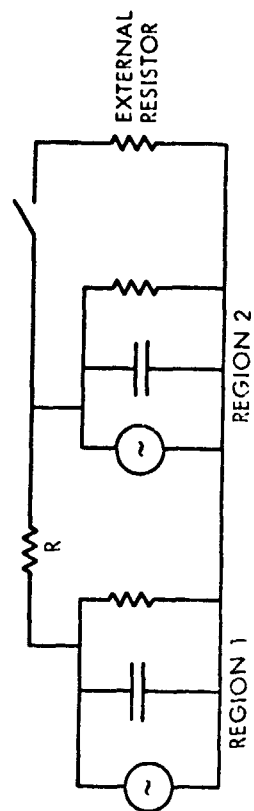


FIGURE 112

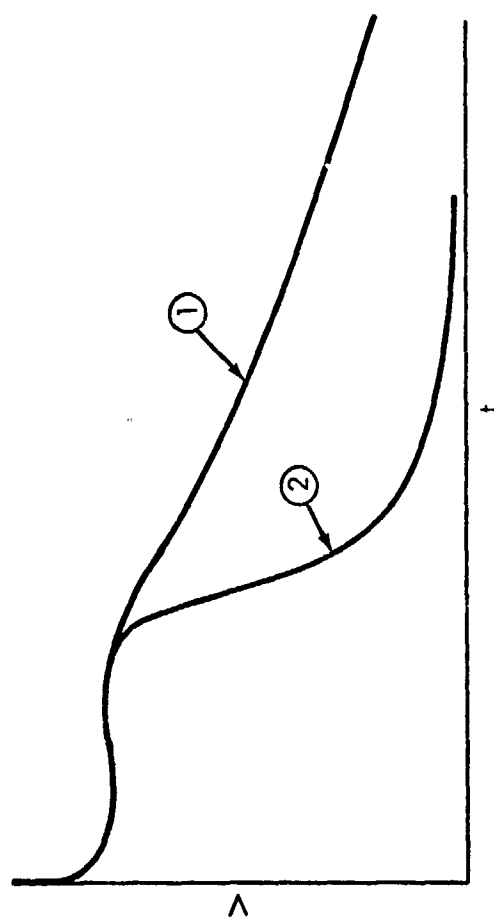


FIGURE 113

dh 56

So, the rate of recovery of this cell, the one with the high current, the one with the resistance in the electrode, will give you a very fast recovery, because it's operating off of a higher current input. So I think the major point that I want to make is that probably the open circuit voltage, until a lot more work is done should only be used as a method of looking for shorts under fairly well controlled conditions, such as measuring after a definite period of time, and requiring that the current be less than a certain amount, and then looking at this kind of a profile.

And if it doesn't fit that, then the results that you get should not be interpreted as either the presence or the absence of shorts.

FORD: Okay. Thank you, Dean.

STEINHAEUER: One question back to Will Scott. On this method for overcharge protection or discharge cadmium hydroxide, can we not attempt even in a destructive manner to an inert handling to go after that electrochemically and chemically directly, rather than by these differences?

SCOTT: You're asking, I believe, about a determination, a more direct way to determine excess uncharged negative? Well, I guess so, I hadn't thought about that question specifically, but I presume that -- well, all I can say is there must be a better way than what we have now.

DUNLOP: Well what you do is -- we did it and compared it, the two procedures I'm referring to are the procedure basically described by Dr. Scott, which I don't think became new last year; I think it was really started a long time ago, and the first time this was done was at Wright-Patterson about four years ago, and it was done before then by other people before that time.

So the procedures to do the chemical analysis on the cadmium electrode are very well known; they've been done in many laboratories: Tyco Laboratories, GE Laboratories, our laboratories, and other places; at Goddard, -- and I don't think there's any real problem in doing it.

A direct answer to Bob's question, though, what we did was, we used that procedure where you do discharge a cell, vent it, continue to discharge, measure electrochemically the usable precharge, then remove the plates, run them through a soxhlet extraction, and determine the remaining chemically available cadmium that's in a charge state that hasn't been

dh57

discharged.

And then you determine the total amount of cadmium and then you make a flooded plate measurement, and then you do what Dr. Scott described. You take and you subtract the positive capacity and the electrochemically measured positive capacity from the flooded plate measurement, and you determine the overcharge protection, which is kind of a complicated procedure.

The other way to do it is simply to charge your cell up, vent it, collect the gas until you get an appreciable percentage of hydrogen evolution. You can do this fairly readily, and we've done it, and you get a pretty good comparison on both techniques. It's surprisingly good; we did it in a program where we evaluated these Telsat cells a year ago, and we got very good agreement by both methods. It takes a little bit of time in an experimental setup, but it's actually easier to determine your overcharge protection in this fashion because you don't have to worry about any chemical analysis, so it's a destruct test.

But all you really have to do is collect the gas, and you have to know the free volume in the cell, more or less, it's desirable, and you have to convert ampere-hour equivalent. -- Well, you don't even have to do that. All you have to do is collect the gas and convert it to ampere-hour equivalent and know when you start generating an appreciable amount of hydrogen.

FORD: What's an appreciable amount of hydrogen?

DUNLOP: Well, what we observed, Floyd, when we ran this, and we have the data -- we presented this data to Telsat on their cells, but what we observed was that there was a very gradual voltage climb. In which you don't see any large percentage of hydrogen involved, less than one percent, and it's hardly measurable in your gas petitioner. And you're collecting your oxygen all this time.

When you get up to, your voltage continues to climb to about 1.6, 1.62 volts. 1.62 probably is a good number. Before you really start seeing an appreciable percentage of the current that you're putting into the cell being converted into hydrogen. And at that time, the voltage starts accelerating, up to about 1.65 volts, to 1.68 volts, and then levels off, and at that point, you're generating an appreciating an appreciable amount of hydrogen.

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The problem you have as an experimenter here is to identify exactly where you hit this point that you identify as the hydrogen evolution point. That's making your cell negative limited. It's not exactly -- you just have to go through this and set a couple limits, and we'd be glad to provide somebody all this data. And I think that it's not too tough to come within the same kind of accuracy, in other words, plus or minus 1 ampere hour, type, or plus or minus 5 or 10 percent, if that's acceptable, you can achieve these kinds of numbers.

SCOTT: Yes, I agree that if, say, chemical analysis is done along with the electrochemical determination, that you can get a lot closer to the right answers. My point that I made before is only that the existing procedure, as promulgated by the NASA spec, does not contain any chemical analysis, and therefore the results obtained by that procedure can be in error by whatever the deficiency of the electrochemical measurement is, and that can be considerable.

And right now, the way the calculation is made, that entire error comes out of the calculation and gives you a corresponding overestimate of the discharged excess negative. And that I think is bad.

BELOVE: Dr. Belove, Marathon Battery. Dr. Scot asked about the origin of that charge-retention test. Perhaps I can help there. As I recall, it started many, many years ago as a result of some very poor charge retention in a group of cells. It was later discovered that this charge retention was due to the fact that copper had been included in the cells, had gotten through the separator, perforated the separator, and created a short condition. And this test helped to pick out very quickly those cells which had copper in them.

As I see it, it may also be used to pick out a cell in which silver has migrated; silver that's sometimes used to braze the ceramic to the cover. It may help pick out a short due to silver migration. As far as the uncertainty of the test, it was mentioned that the history, the past history of the cell is important, and obviously it is. We have seen many cells that appeared to fail pass in later tests, but I wonder sometimes about the effect of what we call a short. Whether that isn't an effect.

It's obvious I can put a piece of wire on there that's 2 inches long, and another one can use a wire a foot long. We call it short, but that may have some effect on the

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time it takes for the voltage to recover.

GASTON: Gaston, Grumman. I have a comment. I agree and disagree with Dr. Scott's comments on the high volt systems short tests, or the voltage buildup test. My experience on the OAO cell, I used to hide the voltage buildup; I didn't use the positive charge and the voltage decay test.

I recall in two instances where the voltage did not build up to the 115, and we took the cells apart, and we did find the cause of the short. So, as an acceptance test, I found it a very sensitive and a very useful test.

I also agree it should be repeated at least once. There's always the possibility that somebody passed by and did drain the cell, or there was some external short so it should be repeated twice. But in each instance where we discovered this low voltage buildup, we repeatedly got again this low voltage buildup. Also, I agree it has to be under controlled conditions, and the cell has to be fully conditioned.

And as far as draining the cell, I think if you use a DVM or any high resistance voltmeter, you shouldn't have any problems in getting this test. I find this a very sensitive and useful test.

STEINHAUER: I wonder if Harvey Seiger has some comment with regard to this delay in the voltage recovery, the lower right hand graph that Dean Mauer put up.

SEIGER: Yes, it seems that -- well, you can look at some of the data that's in Crane, and some of the things that I've done, and apparently there's an effect on the amount of precharge in the cell that will affect that voltage decay and I'm not prepared right now to say which way it does it.

I've noticed with some of the data that came out of NAD Crane, particularly on some 100 ampere cells that there was one cell in particular that failed that so-called short test. And yet that was the cell that on the subsequent overcharge test had the highest voltage. And it seems a little inconceivable to say well, this cell has a short. Because if it had some kind of short in it, would we not expect the voltage to be a little lower instead of a little higher?

That particular cell also had the greatest capacity.

dh60

And in all other respects, it looked like the best. Well, I don't like the short test, because frankly, I don't understand it. I can't write the chemistry for it. I look at the negative electrode, and I realize that when you put that short on, the positive must come up to the potential that the negative is on when the current falls off to a low value. I just don't understand it. I can't write what's going on at that positive electrode.

I also understand -- I haven't done this -- but if the short is kept on and somebody watches the potentials, that the potential of the negative eventually comes back to where it should be -- where it's expected to be. And that would mean that the positive has to come down to the potential of the negative, and things happen then.

FORD: Just one comment in regards to your statement on the overcharge. When you consider the magnitude of the short you're looking for here, we did some tests on some 6 ampere hour Gulton cells three or four years ago, where we looked at the effect of various resistors on this recovery, we found in all cases, once you got above about 400 ohms, the cells would recover.

In other words, I'm suggesting the sensitivity -- it's pretty high resistance-wise. Consequently, you put a 400 ohm across the cell on overcharge, you're not going to see the difference to another cell.

SEIGER: The test as used, I believe, will pick out a short. However, when you hit an example such as Dr. Scott was elucidating, where you run it a second time and it passes then, I just can't conceive of the short, say, with migration of silver across the ceramic, of disappearing then.

So it will pick out a short, but a failure doesn't mean that there is a short.

FORD: Granted. It's not perfect. The point in elaborating further on what Steve said. We found out also that that -- in the particular cell, one particular cell I remember that this open circuit stand, the cell would pass it sitting on the bench, like it's normally tested. But once it was put in compression, as you would package it in a battery, it no longer would pass the test.

So if you are going to be -- that's another input that the test should be run, while at the cell level, if you're

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giong to have the cells packaged into some preload, you should be simulating that preload when you run this test.

LACKNER: Lackner, Canadian Defense Research. I'd like to make a comment. We do use this test, and we do call for it in our spec, where we shorted out, preferably for two weeks, and then look for open circuit recovery.

The reason we've called for this particular test is not necessarily for a mechanical short as such, but we're trying to do a very rough test on the nitrate impurity that happens to be in the cells. Because there is a nitrate-nitrite shuttle which can be a self-discharge reaction on the cells.

Now, in the manufacture of the plates, we do make it from nitrates; nickel nitrate and cadmium nitrate, and if that conversion from the nitrate to the hydroxide isn't quite complete, and it doesn't require too much of an impurity, you can get a shuttle. Now as long as you cycle these cells, that nitrate that's in the solution is not going to bother you.

But if the cell is exposed to high temperature, or is discharged for any length of time, it will get into a condition where it won't come back, and this gives us a rough, non-destructive method of the nitrate impurities.

FORD: Any comment on that comment?

BENE: Jim Bene, NASA/Langley. With regard to the short test, very recently we ran 50 cells, and we used the Goddard short test or recovery test, and none of the cells failed. After that, then we shorted the cells for a long period of time, open-circuited them, they did not recover. I think the highest cells ran about .29 volts.

And then following that, we charged them at C/10 for about 3 minutes, and all the cells went up about 136, 137, and we let them on open circuit. And all of the cells stayed above 1 volt except two, and those two were very nice decays; headed down to .3, .2 volts. Which seemed to indicate either there was a minor short in the cell or a nitrate problem.

I'd like to hear more discussion on this, because I think this is a very sensitive area, and if the test can't show something that is wrong with the cell, then I think we ought to get to the bottom of it.

SCOTT: Amen.

dh62

FORD: Comments?

SEIGER: I have a question of Dr. Casey, who discovered the nitrate shuttle. If the potential of that positive electrode is decreased, would the nitrite be oxidized by the positive electrode?

CASEY: Casey, Defense Research Board. The honest answer is I don't know. I forget the numbers. The reversible potential of the nitrate-nitrite couple in KOH compared to the nickelous-nickelic reversible potential under conditions of very small amounts of nickelous.

I don't think you asked a fair question.

(Laughter.)

SEIGER: I apologize.

GINER: Jose Giner, Tycc Laboratories. I want to make a comment on electrochemistry. And that is when you try to do a test like that, you are involved with rest potentials, and rest potentials are very unreliable. And they are unreliable because of impurities in solution, the nature of your separator, additionally, liberation of oxygen can affect very much the potential of the particular electrode.

So you may have a perfect cell that never recovers because you have the right or the wrong impurity. I think that the rest potential is a very bad way of using this for a criteria for this type of thing.

FORD: Yes, I said it's not perfect but I haven't heard anybody offer a solution. That's what I'm looking for.

LACKNER: You just said why we should use the test. To pick out the impurities. We're not interested in the potential. Potential can be found by electrochemists and pure media. We're interested in the voltage of the cell.

GINER: No, my point is that if you change the construction of the cell to change the nature of the separator, you have more oxygen there. Anything that you do there may change your potential without telling you really what the result is. In other words, you can have a cell that is -- and I think that could be a perfect cell.

STROUP: Stroup from Goddard. The effectiveness of this test -- someone said that this was a Goddard test.

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And I'm afraid I have to plead guilty. But the way Goddard runs that test is considerably different from what most people in this room run it.

The history of the cell -- before you allow it to stand for voltage recovery, has to be done in a prescribed way, and what we do here is we charge the cell for at least 16 hours at C/10 rate, then we immediately discharge it. Short it out overnight, and let it stand open-circuit, and then you watch the voltage recovery.

Now if you use this kind of regime, we have found it's worked satisfactorily. For instance, on the OGO battery, we were asked to check four flight batteries, and two of them failed this test. On failure analysis of one cell, in one of these flight batteries, there was a metal particle embedded in the separator material, causing a very, very low rate type of discharge of the cell.

I don't know any other way we could have found this particular problem. On capacity measurements, the cell checked all right. On many tests before, it checked all right. This was the only test that it failed. We're still using the test, and I presume we will continue.

FORD: Other comments?

I'm still waiting for the solution. An alternate.

No, I agree. It has pitfalls. But it's worked we have detected failures. If we only get two out of a thousand, then that's better than missing those two. And until you come up with something better, don't expect to see it change at this point. I mean, that's all I can say. I'd like to see it improved.

DUNLOP: I think I know the answer, but you do make impedance measurements using that meter, Hewlett-Packard meter you have, right?

Did you make impedance measurements on these particular cells? Did you see anything?

FORD: You're comparing megabucks with pennies.

SEIGER: Well there's something that I've never tried, but I've been wondering about since Don was talking to me about this recently. I was wondering whether instead of bringing the cell down to a zero potential, why not bring it down to about a half a volt and put a silicon diode across

dh 64

and keep it about .6 volt for a period of time, and then see what the recovery is. In this case, you will not be bringing the positive electrodes to the potential of the negative.

FORD: Good suggestion.

SCOTT: Scott, TRW. It seems that maybe the least that one might do to improve interpretation is to a), to continuously monitor the voltage during the short-down, as Dean suggested, but then also continuously monitor the voltage during the recovery period, open-circuit, so-called open circuit period.

And then you can look at the whole shape of the curve, and be in a better position to tell what you've really got.

PASCALL: Pascall, Marshall Space Flight Center. I want to amplify some of the experiences we've had. Like Goddard, we use this charge retention test, or summer test, maybe the hours that we leave on short there are somewhat different, but it's basically the same test.

We have tested a large number of ATM batteries, 20 ampere hour cells, and this test is run twice; once at the cell level, and once at the battery level. And in a number of cases, we have found that we have passed the initial test at the cell level and have failed a cell at the battery level.

Upon analysis, we have found that this cell would not hold a charge after subsequent cycling. It's true that in some cases this test does not always give a good indication of a failed cell. There are a few cases where the cell is eventually approved is good, and the other cases where we have found a failed cell, of course, it's been obvious by the fact it would not hold voltage on subsequent testing.

In fact, we have found failed cells in flight-type hardware of course, makes this test very valid.

FORD: Thank you.

SHAIR: Bob Shair, Motorola. I wonder if you would see a difference between cells that have an electronic short and cells which are discharging by this diffusion process.

dh 65

If you monitored the current while you had this short on. I would think that the decay of current would be different with an electronic short then if it were just a decay of current as the plates are running down by the diffusion mechanism.

FORD: It sounds like an interesting possibility.

I think one missing link right now is at the end of the 16 hour period, it's -- all it is is 16 hours, there is no maximum voltage on this cell, or minimum voltage. There's no voltage specified whatsoever.

And we have results that, particularly where cells have been subjected to this type of test after long term repetitive cycling, and the type of thing that you see, on a new cell, you get a very sharp drop-off of the voltage after one volt, or after 1.1. But with the onset of the decay of this type of -- with the voltage with cycle life, you don't get the same short drop off.

So, to stop at one volt and put the resistor across is not the same reference points. We're very much aware of this, but we're not sure how to tackle it. It goes back to some of the things that Scott said earlier.

We know that it's somewhat dependent, or in some cases, very dependent on the previous history of the cell.

MAUER: I think if you demand that the voltage or the current at the end of the short period be less than a certain amount, then I know of no way in which the voltage -- in which a shorted cell could pass the voltage recovery test. If you allow that current, at the end of the shorting period, to be anything if it's high enough, then a shorted cell can pass it.

So if you put that additional restriction on, you should be able to screen out all of the shorts. Unfortunately, you'll screen out a few non-shortened ones, but your reliability of the passed cells should be very good.

Now the other thing is that there's been several comments here on a recovery test, and then subsequent other things, and then another recovery test, and cells would pass the second one and not the first one. Things have been done to the cell during that period. You may have a short in one case and not later on, or vice versa. So you have to be very careful about how you compare the two tests on the same

dh 66

cell.

MC CALLUM: McCallum from Invention Talents. It seems to me you're talking about dead shorting these cells, and then measuring your recovery, always leaves you in a state of uncertainty of what you had at the end of that time, and hard to interpret from a physical viewpoint, whereas the charge retention test that I also hear being mentioned, where you might put a quantitative small amount of Coulombs in, and then see what you get back after a little time. It seems to me that that's more indicative of whether you have a short or not. Which one are you really using here at Goddard?

FORD: What we refer to as the "open-circuit voltage recovery test."

MC CALLUM: Yea, and you short that out, and then you wait --

FORD: No, no. Let's back up a minute. There's never a dead short on the cell. It's a --

MC CALLUM: It's shorted overnight, you said.

FORD: It's a half on resistor, for 16 hours.

MC CALLUM: And then you take that off and measure how the voltage comes back up.

FORD For 24 hours.

MC CALLUM: Yea. I think you'll always have controversy about that test. Whereas if you, at the end of that time if you were to put in a small amount of Coulombs -- or short it before you let it stand overnight, and then see what happened with the little bit of charge you put on, I think is open to interpretation, understanding.

FORD: That's the controversial part, too. Is interpretation of the results after you put the charge in. Incidentally, we did have a situation where we compared the two tests on a cell that had failed the open circuit. And it failed the open circuit consecutively. But it would not fail the -- I hate to use the word "standard," -- but a charge retention type test that you're referring to. I think it was a C/10 for five minutes. Did the cell pass that test?

Basically I feel that the open circuit voltage is

dh67

a more sensitive test than the test like you're suggesting. Or that has been done in some cases.

MAURER: I agree, Floyd, with the open circuit recovery. The open circuit recovery is more sensitive. With the short charge, you're putting in a certain number of Coulombs that you would otherwise have relied on the positive electrode to supply. And therefore you will get up the voltage recovery curve that much faster.

Now, the size of the resistor, or the size of the short, that is, the resistance of the short that you can detect by these two processes will be different. Now maybe, you might say, that that size difference is insignificant. You don't really care whether you have 100K or a 1 megohm short in the cell, and we all know that we've been able to operate cells with fairly heavy shorts on them successfully if we use high rates.

So, just what size short you want to detect is open to question, I think.

DUNLOP: I think this may be in line with what Dean Maurer just said, but one way to run this test -- I think basically that the parameter that you're trying to identify -- that's why I think I'm repeating him -- is if you have a partial short in your cell which is going to have a significant effect in the performance. And one way that strikes me -- a typical discharge of an Intelsat IV cell for reconditioning, is to slap a fairly large resistor across the battery pack, for a number of cells.

And it takes 60 hours or 80 hours or some fairly large amount of time for those cells to discharge. Now if you actually do this, if you slap a resistor across a bunch of cells, fairly large resistor. If those cells are fairly well matched, they do come down very uniformly. If you have one cell that has any type of a leakage pass in there, you definitely should be able to detect it in that kind of a test. And it doesn't take any longer than the type of test you just identified. Doesn't take more than a couple of days.

It should certainly identify whether or not you have some small leakage path in your cell.

CASEY: One possibility that has been tried in some laboratories is to pass a high current through these cells, several tens of C rate for a very short time, and make a big short out of a little short. Then you have something to work with.

dh68

with.

(Laughter.)

This does have the advantage of selecting, very quickly, the good cells from the weak ones. But it raises the question, which I think is more fundamental, that of the specification and the selection of the separator material. The shorts occur because of the weakness. Little holes, little pinholes, little cracks, little bulbous collections of gas or liquid within the separator material, which can be shown up by certain kinds of photography.

Now, the specification and the selection of separators, with respect to the number and kinds of defects in it per square inch hasn't been talked about in the last day and a half, and I think it's fundamental, and perhaps somebody would like to describe how they do select separator materials for inclusion in these batteries. There's where the root problem of the shorts arises.

PALANDATI: Charlie Palandati, Goddard Space Flight Center. I was just curious, Floyd, in regards to putting a resistor across the cell, in the specifications, is it spelled out, the tolerance of those resistors? Are they all one percenters? Half percenters? Ten percenters? Is it possible that some of the variables that you notice between cells, is it possible you suddenly have a cell here with a ten percent tolerance on the resistors, and this is where your variables are coming from now, due to the fact that there are two different shorting currents on the cells? Two cells, with two resistors across them?

MAURER: No, once the cell voltage drops below about .6, the current is limited by the diffusion rate, and you'll measure the same current through a one-ohm resistor as you do through a dead short.

PALANDATI: Thank you.

STROUP: I'd like to ask Dean Mauer, have you all tried this open circuit recovery test, like Goddard runs it, like the one I described?

MAURER: Yes, that's the one that we normally use.

STROUP: I mean, did you try it -- in the manner in which I described it.

dh69

MAURER: Yes, we normally give a cycle, and then a 16 hour short, and then we use an 8 hour recover. Eight hour usually brings you to the peak of the voltage recovery.

STROUP: You charged it at C/10 for more than 16 hours, and then you shorted it all the way down. I don't mean you shorted the cell, but you discharged it at the C/2 rate, and then left it shorted overnight with about a .2 ohm resistor.

This is what our information describes it, in the Crane reports. Crane uses that same test, and they describe it in every one of their reports.

MAURER: Ours is slightly different; we would charge with C/10 for 16 hours, discharge usually at perhaps a five hour rate to 1 volt, and then follow this by a 1-ohm resistor.

STROUP: Then we must agree, then, the test is different.

MAURER: Right.

STROUP: We have tried, I think very carefully every test I've heard described here tonight on the OGO cells, the flight batteries in particular, because I think everyone here realizes that gravity, when you're faced with a flight battery, and making sure that thing is going to work, because you're not going to climb up there and change the cells. We've run every test that's been mentioned here this evening, and there was only one that turned up those two failed batteries out of four that we checked. And that's a matter of record.

FORD: Dr. Casey, I see nobody took up your challenge on the separator.

It's a few minutes after one, and we have to be at the cafeteria by 1:15, so we'd better break for lunch at this point.

(Whereupon, at 1:05 p.m., the hearing was recessed, to reconvene at 2 p.m., this same day.)

AFTERNOON SESSION

(2:15 p.m.)

FORD: It was indicated to us this morning by several different parties and again during the lunch hour that some of you come particularly to hear the development on the nickel hydrogen work and I think we have one on silver hydrogen work, so in order to accommodate those people who are especially interested in this technology, we're going to defer the rest of the papers we had scheduled for this morning and go right into the nickel hydrogen and the silver hydrogen work and then come back and pick up where we were at lunch today.

So at this time Jim Dunlop will take over the session.

DUNLOP: Thank you, Floyd.

I've been thinking for two days of some momentous statement to make when I came up here, like something to the effect that there's some good news and some bad news. And I think maybe there is some good news and I don't really think there's any bad news.

It's just after talking for a day and a half with all the nickel cadmium people and I think the nickel cadmium people have a number of additional papers to go this afternoon. I don't want to shake their world too badly. But there is some good news. We have come up with a series of cells that are hydrogen cells that do have some interesting potential, particularly right now for aerospace application, and what we're going to do in this session today is identify the work that has gone on in the nickel hydrogen and silver hydrogen technology over the last year and a half.

This is a new technology. It really started about a year and a half to two years ago when -- I think it really started when it was conceived of in a meeting where TYCO and COMSAT, representatives, individuals from TYCO Laboratories and COMSAT, were talking about methods of improving energy density and the idea of a sealed nickel hydrogen cell was brought up and we decided it would be interesting to try and put it to practice to see if the idea would work.

And the first cells were actually put to practice in the COMSAT Laboratories and under this contract with TYCO. Since that time there has been a fair amount of work on the part of Energy Research Corporation who have made a number of interesting contributions, too, and have developed some interesting technology and as I understand it now that Philco Ford has been doing quite a bit of work primarily on the silver hydrogen.

LN2

Actually the nickel hydrogen cell really is a culmination of the nickel cad technology and the fuel cell technology using the hydrogen electrode from the fuel cell and if I could have the first slide, please.

(Slide 114.)

These are the reactions that occur in the nickel hydrogen cell and what we have shown here is the normal operations overcharge and the reversal. During normal operation at the positive electrode on discharge you see that the nickel OOH is reduced to nickel OOH_2 on discharge. It's a conventional nickel oxidation reduction equation that you're all familiar with.

At the negative electrode the OH ion produced at the positive electrode combines with the hydrogen gas to form water and the net reaction which is shown there is the hydrogen reducing the nickel COH electrode to nickel OH_2 .

One of the interesting things that got that net reaction is that there's no net imbalance of water; even in the nickel cadmium cell as you know, everytime you discharge the nickel you do consume water molecules.

In this case there is no net imbalance with water but there's a mass transport of water from the negative back to the positive on discharge, which is the same kind of mass transport that you observe in other cells but there is no net change and that means there's no net change in the electrolyte concentration for normal operation.

Now on overcharge at the positive electrode, you are going to get the OH ion producing oxygen. The big question was what's going to happen to this oxygen and hydrogen cell. Well, what happens, it turns out, is that the oxygen recombines here at the negative electrode, recombines with the hydrogen to form water and this recombination, the rate of this recombination, is so fast that the partial pressure of oxygen built up in the cell on overcharge even at two or three C rates at room temperature, is less than 2 or 3 percent of the total partial pressure of the cell.

We've even run -- we did it really to show Goddard -- but we ran tests where we operate cells at continuous overcharge at zero degrees Centigrade where we're using charges rates of C/2 at about a 50 percent overcharge and we've run cells for a couple hundred cycles in this kind of a mode and

ln3

we've even gone up to C rate overcharge at zero degrees Centigrade continuously for many hours with no pressure buildup in the cell.

Again, on overcharge there is no net buildup or loss of water in the electrolyte. When we go into reversal, we have just the hydrogen. We produce hydrogen at the positive electrode and consume it at the negative electrode and again there's no net imbalance of water. So this turns out to be interesting that we've run these cells continuously on overcharge and continuously in reversal and neither mode does anything to hurt the cell. So this is the only cell that I really know of that can be run in the sealed configuration both in the normal mode on overcharge and in reversal without building up any pressure in the cell, building up any pressure over the normal pressure that you would expect in cycle.

So what we suspected would happen was proved and the actual cells that we constructed -- to show you how these first cells were constructed I'd like the next slide, please.

(Slide 115.)

These cells were constructed with the sintered electrode or pressed electrodes as the case may be and these electrodes that we're using are just commercial electrodes provided either by GAF, GE, or Eagle Picher and ERC. We've obtained electrodes from all these manufacturers and cycled them.

Now, for the sintered electrodes we've been using this Hercules separator material; that's the same separator material that was described by Tom Hennigan. It's the 1-1/2 ounces per square meter and we've used this in all the sintered electrodes and we've actually had no problems to date of any kind that I can identify with that particular separator.

We use conventional platinum electrode for the hydrogen electrode. That's a standard type electrode that's used for the oxygen electrode in a hydrogen-oxygen fuel cell, or oxygen or hydrogen; it doesn't require any electrolyte storage in this particular case. It just has to be a very thin lightweight platinum electrode and that platinum electrode generally has a current density capability at least an order of magnitude greater than the current density capability for a nickel electrode with very little polarization

LN4

losses. Typically, these hydrogen electrodes are operated at 100 to 200 milliamp seven years squared (?) and the electrolysis of fuel cell modes when they're used that way in the hydrogen-oxygen are for the electrolysis itself. It doesn't seem to be any problem.

The other point about that hydrogen electrode is that at the potential that it operates at there's absolutely no migration. We run these hydrogen electrodes for a thousand cycles, take them out and put them in another cell and run them for another thousand cycles. We don't have any problems at all with the hydrogen electrodes. Our problems now, interestingly enough, are with the nickel electrode. One of the big advantages that you can see this cell potentially offers is that all these discussions that we've had for the last day or so in regard to cadmium migration, the intermediate soluble specie of the cadmium during discharge, the migration of cadmium through the separator and so forth, all these things are completely eliminated. We don't have any of these problems in this particular cell.

Next slide, please.

(Slide 116.)

These are sample cells that we've operated. Another thing that's surprising about this program is the first cells we ever put together ran over a thousand cycles and that's a big surprise if you work with the new combination of electrodes. You just don't normally expect to get that kind of operation. These cells are generally running -- you can see by these gauges -- 50 psi and 200 psi hydrogen pressure during the cycle. The pressure range is around 100 psi.

Possibly some of my colleagues would want to find the pressure range that they intend to operate when they talk about their respective cell designs. This was just done -- is just controlled by the amount of free volume that we have in the cell and the ampere hour capacity of the nickel plates that were put in there.

But the point here is that these cells in this configuration have operated for about a year and a half now. We've tried a whole raft of different electrodes. We've tried -- and we don't know yet exactly what the limitations are.

NI-H₂ CELL ELECTROCHEMICAL REACTIONS

NORMAL OPERATION

DISCHG	DISCHG
POSITIVE	$\text{Ni(OH)}_2 + \text{H}_2\text{O} \rightarrow \text{Ni(OH)}_2 + \text{OH}^-$
NEGATIVE	$\text{H}_2 + \text{OH}^- \rightarrow \text{H}_2\text{O} + \text{e}^-$
NET REACTION	$\text{H}_2 + \text{Ni(OH)}_2 \rightarrow \text{Ni(OH)}_2 + \text{H}_2\text{O}$

OVERCHARGE

POSITIVE	$2\text{OH}^- \rightarrow \text{H}_2\text{O} + \text{O}_2 + 2\text{e}^-$
NEGATIVE	$2\text{H}_2\text{O} + 2\text{e}^- \rightarrow 2\text{OH}^- + \text{H}_2$
NET REACTION	$\text{H}_2\text{O} \rightarrow \text{H}_2 + \text{O}_2$

REVERSAL

POSITIVE	$\text{H}_2\text{O} + \text{OH}^- \rightarrow \text{H}_2 + \text{O}_2$
NEGATIVE	$\text{H}_2 + \text{OH}^- \rightarrow \text{H}_2\text{O} + \text{e}^-$

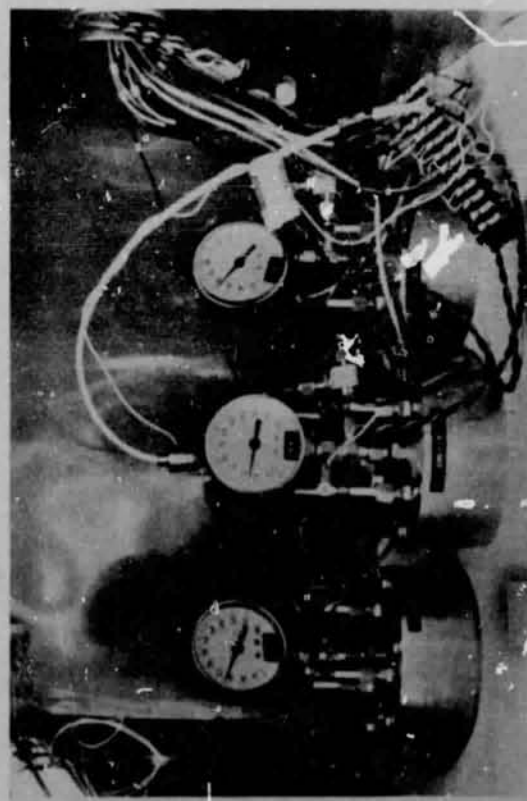


FIGURE 114

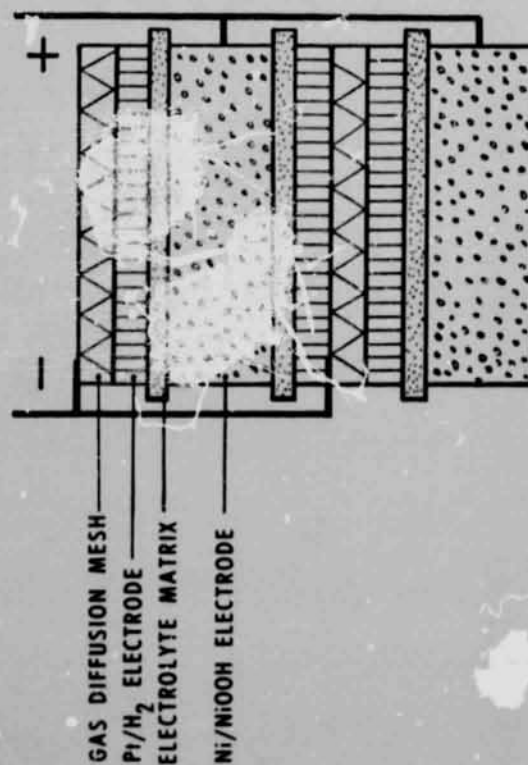


FIGURE 116

FIGURE 115

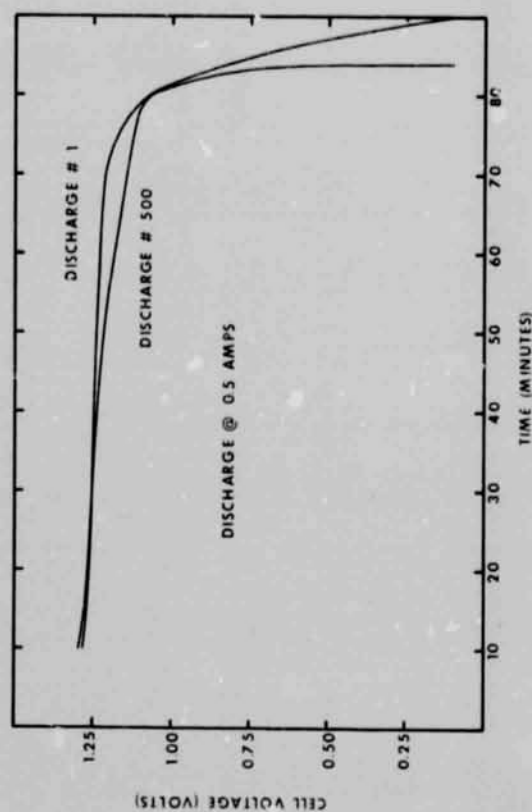


FIGURE 117

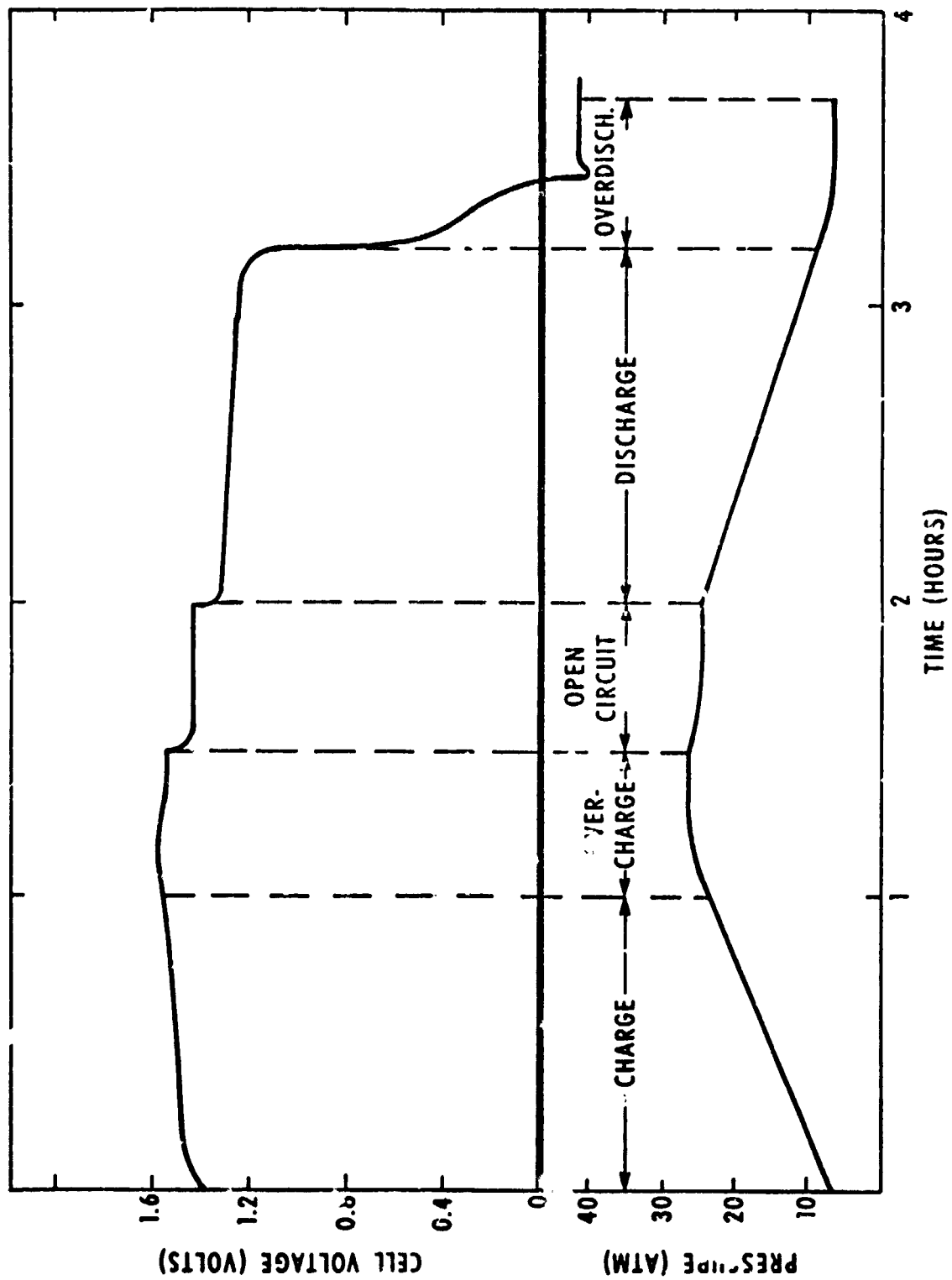


FIGURE 118

ln85

But what we're beginning to do is we're beginning to find -- it's very clear that the nickel electrode is our limiting electrode. These cells were run generally around 20 degrees C with the 30 percent overcharge at 70 percent depth of discharge up to and exceeding a thousand cycles for most of the electrodes that we're looking at now.

Next slide, please.

(Slide 117.)

This is a typical cell voltage versus time for a sintered electrode. The data shown here is Discharge No. 1 and Discharge No. 500. To make this clear, the curve for Discharge 500 is up here. This shows a slight increase in positive capacity again that was described as an example by the work that Ford exhibited just before lunch.

You see a slight increase in ampere hour capacity with cycling and the voltage characteristics of the nickel hydrogen are very similar to the nickel cadmium. The voltage for the nickel hydrogen cells is actually slightly higher, 20, 30, 50 millivolts higher.

The next slide, please. I think this is my last slide.

(Slide 118.)

This is just to show the voltage as a function of time at the C rate for all these different modes that we've been describing. Here the cell is being charged. This is the pressure and that's the cell voltage as a function of time. It's being charged at a C rate so it gets charged up in about one hour. You see the voltage climb up.

This is the overcharge portion. You see when the cell gets overcharged, you see the pressure comes up and levels off right here. You can actually run at C rates for days like that but for this particular slide I'm just showing an hour or two.

Then we go into this open circuit or stand condition. There's a slight dip in pressure there and I should point out here that there may be a self-discharge mechanism here but we've had these cells on open circuit for several days and we do observe a slight loss in capacity with days.

LN6

After about one day you get a loss of about 15 percent or something in the ampere hour capacity. It may be that hydrogen does react in the nickel electrode to reduce it chemically but if it does the reaction is so slow that you can hardly see it happen and people who are familiar with nickel cad technology, you know that there's no rapid way to get rid of hydrogen in the nickel cad cell.

The big point here is that there's no requirement for any gas separation in this cell. So it's one of the major drawbacks of the hydrogen-oxygen fuel technology is that you do have to have gas separation. In this particular cell, everything I've said to date is that there is no reason that you have to have gas separation so your separator doesn't have to do anything more than maintain the electrolyte in it. It doesn't have to provide that gas separation. That's the major drawback with the hydrogen-oxygen cell.

During the discharge, the pressure drops off as you would expect. And another point here is that the pressure is an absolute indication of the state of charge. You could absolutely completely minimize any overcharge if you wanted to or you could use this if you have an application for a state of charge indicator. So you know, not only when you're fully charged, but you know exactly what the state of charge of your cell is at all times so you use the pressure for that reason.

Here you go into reversal. This is overdischarge. We've run this for days too but all you're seeing here is the voltage come down and level off and the pressure just levels off and this is just the hydrogen. Now you're pumping hydrogen from one electrode to another. That's it for my presentation.

SEIGER: Seiger of Helictek. You mentioned that the self-discharge was about 15 percent after one day. Did you get any additional self-discharge after the one day and could you tell us the rates, please.

DUNLOP: I don't offhand remember. It seems to follow that same exponential pattern that you normally observe in a nickel cad cell and I do think that possibly one of the next speakers may want to elaborate on it because they have obtained a significant amount of data for this mode of operation.

By the way, on that particular point, let me say that there have been a couple papers presented on this subject just recently. This was the first time. There was a joint

c. 2

L47

paper with a couple of my colleagues, Joe Stocco and Vanomering and the TYCO Laboratories, Larry Sweeney and Lou Gains gave a paper, joint paper, in that energy conversion conference.

And then LRC had a paper by Marty Klein in that conference. So there are a couple papers out that serve as a good reference that cover most of the, actually, all the points that I have made in considerably more detail.

FORD: Is that satisfactory, let's give all the three papers and then open it up for general questions across the board?

DUNLOP: Yes, because there's probably a lot of questions that would be answered by doing that.

Next I'd like to introduce the next speaker, Larry Swette from TYCO.

SWETTE: Jim has covered quite a bit of territory in that introduction. I'll run through some of the same areas. Perhaps I can add something and he perhaps can see a slide or two that looks familiar.

Could I have the first slide?

(Slide 119.)

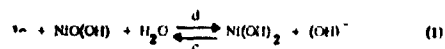
As Jim said, the positive electrode is a typical nickel electrode and operates in a typical fashion. The differences from the nickel cadmium cell is that the negative is a thin, lightweight electrode that's capable of consuming and evolving hydrogen.

The net reaction is as shown with no water involved in the overall reaction which is a significant advantage. The cell is intrinsically positive limited in charge. You have a limited amount of active nickel material, whereas the negative can continue to decompose water to form hydrogen. The cell can also be made positive limited in discharge by precharging the cell in the discharge state with hydrogen and typically we put in about 100 psi of hydrogen. Then at the end of discharge, the end of discharge in the nickel electrode, the negative continues to function in the same manner consuming hydrogen and the pressure, of course, levels out if you do into the reversal you have the balanced hydrogen reaction and that occurs at the C rate at about minus 200 millivolts, with essentially no heat generation.

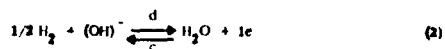
ELECTROCHEMICAL REACTIONS

NORMAL OPERATION

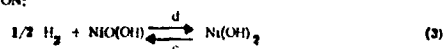
POSITIVE:



NEGATIVE:

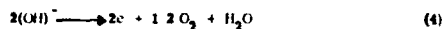


NET REACTION:

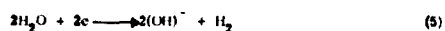


OVERCHARGE

POSITIVE:



NEGATIVE:



CHEMICAL RECOMBINATION:

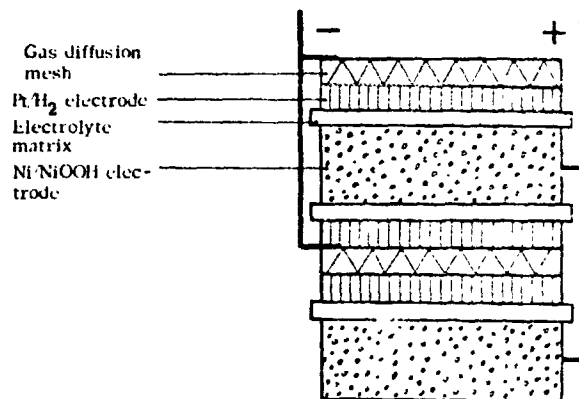


REVERSAL

POSITIVE:



NEGATIVE:



Cell stack configuration

FIGURE 119

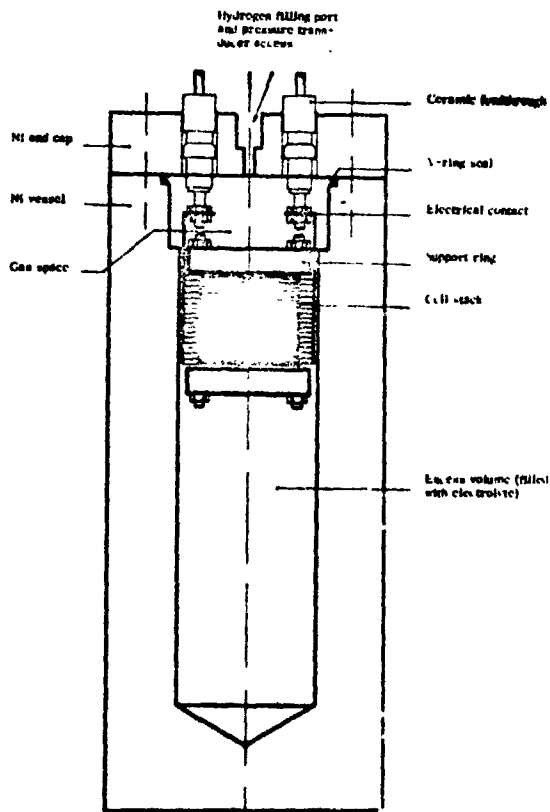
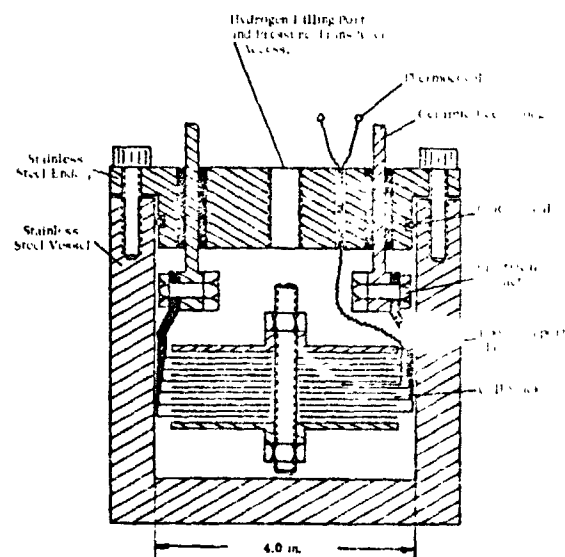


FIGURE 121

FIGURE 120



Ni-H₂ test cell - 9.9 cm diameter plates

FIGURE 122

LN8

Could I have the next slide, please?

(Slide 120.)

I think you can recognize that even upside down. I should point out here that we have looked at only single cell constructions. This is the schematic for a parallel plate construction. The cell could also be assembled possibly as a jelly roll construction and a series of connected cells should be quite simple to arrange also. Because of the over-discharged characteristics, it should also be possible to put a number of series connected cells within one pressure container without any difficulties.

Could I have the next slide, please?

(Slide 121.)

We've been looking at resealable type of pressure vessels for our exploratory experimentation. We've been working on this system for a little over a year. We have here a cell that we can use up to about 2,000 psi. Our system analysis indicates that a desirable pressure range from the energy density standpoint will be in the vicinity of 400, 600 psi, but we would like to do things like study the effect of pressure on the charge retention.

Could I have the next slide, please?

(Slide 122.)

That's an assembled parallel plate stack, about 5 amp hours, 16 nickel plates; and this cell operated successfully for about 50 cycles and then we took it apart to make another cell or several more cells. We're taking Jim Dunlop's word that the thing will really and truly go for a thousand cycles and I have no doubt that it will.

Could I have the next slide, please?

(Slide 123.)

We also made another resealable construction to test larger plate diameters. Again this gets into the system analysis as far as energy density is concerned. The size of the cell that you put together has a pretty direct function by way of the pressure vessel on the energy density. The ideal shape as you might expect is a long cigar-tube type of thing but that would entail assembling a great many electrodes and it's certainly simpler and more reliable to have the

LN9

larger diameter cell and make the construction simpler and the energy density compared to this optimum is not very far off, perhaps one watt hour per pound.

Could I have the next slide, please?

(Slide 124.)

That's the larger assembly. That's a 25-amp hour stack and four-inch diameter plates.

Next slide, please.

(Slide 125.)

This characteristic cycle charging at the C rate and discharging at approximately the C rate also. What I have plotted here is the cell voltage and the temperature of the stack and the pressure in the cell. You can see that we start with a precharged pressure in the cell. Looking at the voltage, we start at about 1.4 volts and we go to about 1.5 during charge and during overcharge at the C rate, we go to about 1.57, 1.6 volts.

The temperature begins to rise just before the end of charge and the pressure throughout the charge is linear and as Jim mentioned is a direct reading of the capacity of the cell at any point. It can also be used to detect the capacity of the cell if it has been partially discharged. When we get into overcharge, it can be seen on the pressure curve that the pressure begins to level off indicating that the recombination mechanism is functioning.

When we're in overcharge it's generating oxygen on the nickel electrode and this is moving to the negative electrodes and recombining there with hydrogen, either directly to form water or by way of electrochemical reduction. It doesn't matter which. But it is apparent that recombination occurs and it occurs very rapidly. We have operated cells from C/10 to the 5 C rate and the recombination was excellent in all cases.

During discharge, the discharge is typically quite flat and the mid-discharge voltage at scale to 1.2 is typically 1.26 to 1.28 volts. There is little temperature effect during discharge and the pressure again is linear throughout the course of the discharge. During overdischarge, if the cell is discharged immediately after charge, we see a plateau at about 8/10ths of a volt which represents the reduction of oxygen stored in the nickel plates during overcharge.

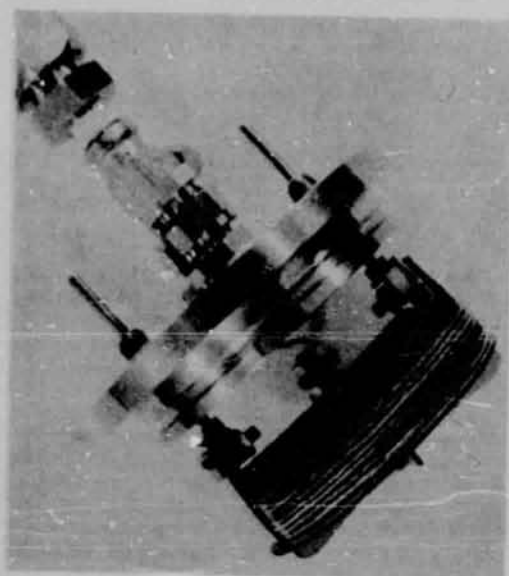


FIGURE 124

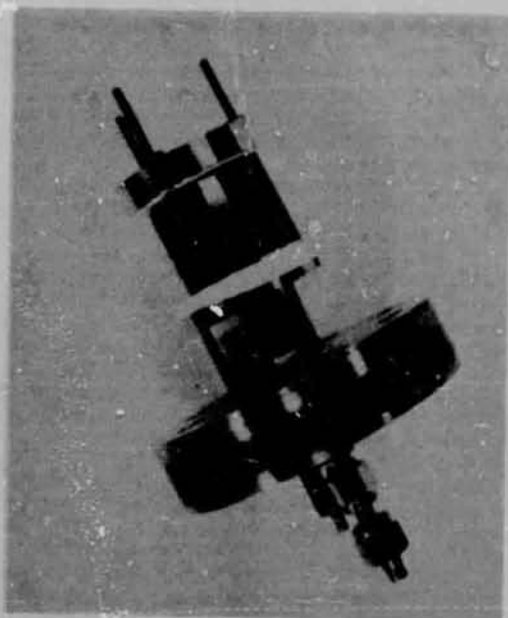


FIGURE 123

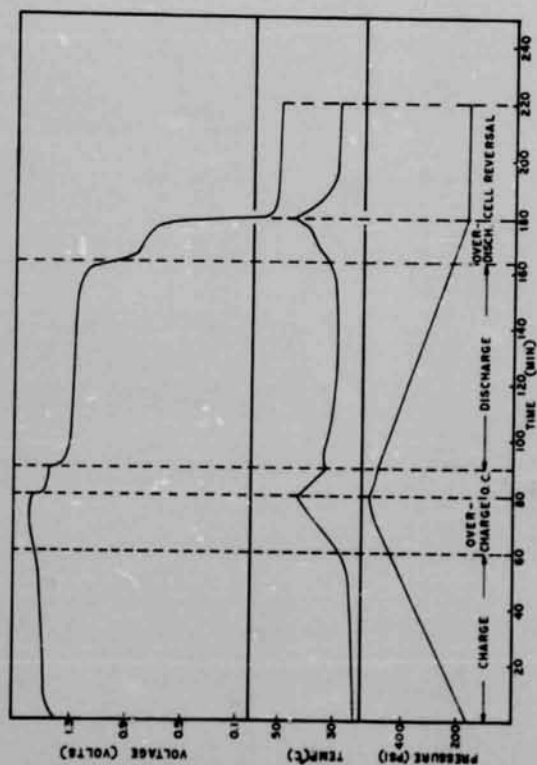


FIGURE 125

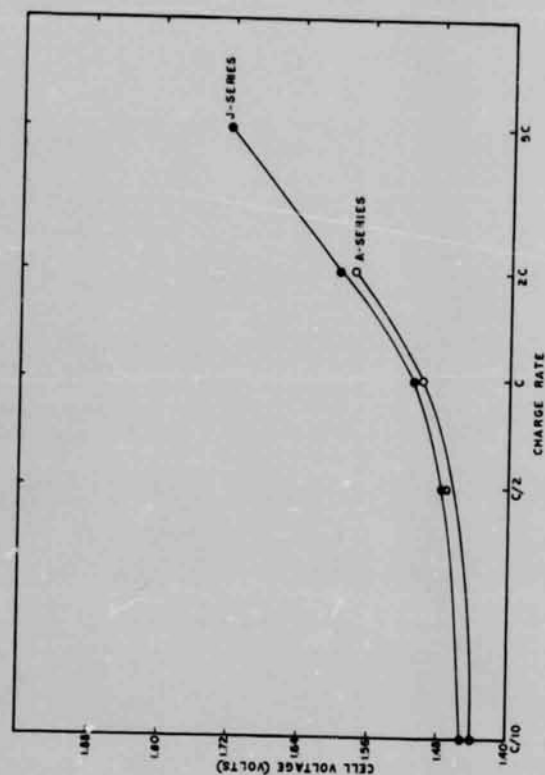


FIGURE 126

LN10

The cell is allowed to stand on open circuit for some time. That oxygen apparently desorbs and recombines and we don't see the plateau. There's also a temperature increase at that point since it's operating in a fuel cell mode, hydrogen oxidation and oxygen reduction of the nickel electrodes. And you can also see that the pressure continues to decline throughout that overdischarge. Then in cell reversal the potential levels out, cell voltage levels out at about minus 200 millivolts. The temperature drops back to approximately room temperature and the pressure in the cell levels out so that at either end of the cycle we have a pressure limitation.

Could I have the next slide, please?

(Slide 126.)

We have looked at charge as I said from the C/10 and 5 C rate and plotted here the mid-charge voltage where it says charge rate and it goes from at C/10 about 1.46 volts to about 1.72 volts at the 5 C rate.

Could I have the next slide, please?

(Slide 127.)

These two series just represent two series of cells that we put together with different electrode configurations, different electrode materials.

During discharge, I plotted here again in mid-discharge voltage versus the discharge rate. At the C/10 rate it's about 1.3, 1.32 and at the 5 C about 1.06 volts. The typical discharge rate for communications satellite operations is C/1.2. Usually we see 1.28, 1.29 volts for that discharge rate.

Could I have the next slide, please?

(Slide 128.)

We have operated the cell on overcharge for extended periods. Here you see about 300 percent overcharge. There is a peak in the cell voltage initially as reaction switches from charging the Ni(OH)_2 to the Ni(OH) , switches over to oxygen evolution and at that point all of the input energy is converted to heat and apparently the nickel electrodes operate a little more efficiently. As they get hotter, the voltage decreases slightly.

LN11

The temperature levels out after about an hour after about 100 percent overcharge. In this case, it leveled out at about 50 degrees Centigrade and that, of course, depends on the heat transfer characteristics of the cell. The pressure levels out during overcharge and it even decreased slightly with time here.

Could I have the next slide?

(Slide 129.)

We have looked at the charge retention of the nickel hydrogen cell. We have two sets of electrodes that we were looking at, what's called there the A Series, the open circles, were prepared by chemical impregnation and the J Series by the Fleischer method.

We thought in the first case that there might be the possibility of nitrate residue in the plates contributing to a nitrate-nitrite shuttle self-discharge mechanism so we're interested in looking at the plates made by the Fleischer method to see if the self-discharge is reduced and that's what's plotted there and the results are really not too clear in that respect, but in general, with regard to the self-discharge, there's about a 10-15 percent loss in one day and as you can see the slope of that line changes quite drastically after that so that after a week the capacity loss is about 50 percent.

Could I have the next slide?

(Slide 130.)

I should mention with regard to Ptolemaic efficiency that we expect the nickel hydrogen cell to perform better at low temperatures than a nickel cadmium cell. One of the problems with a nickel cadmium cell is that we have hydrogen evolution of the cadmium at low temperature. This, of course, is the proper mode of operation for the nickel hydrogen cell. Hydrogen evolution does not occur in nickel reaction. It's the main reaction. So that problem is eliminated.

At high temperature, of course, you have the same problem that you have with the nickel cadmium cell: inefficient charging because of increased oxygen evolution. We've looked at the voltage efficiency of some comparable systems, nickel hydrogen, nickel cadmium, cadmium oxygen and hydrogen oxygen. Looking at the charge voltage at the C/10 rate, the discharge voltage at the C rate, and comparing that ratio.

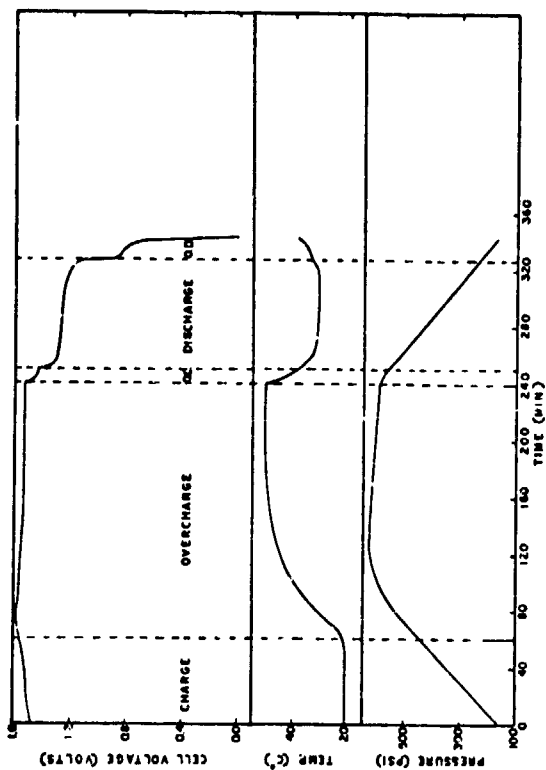


FIGURE 128

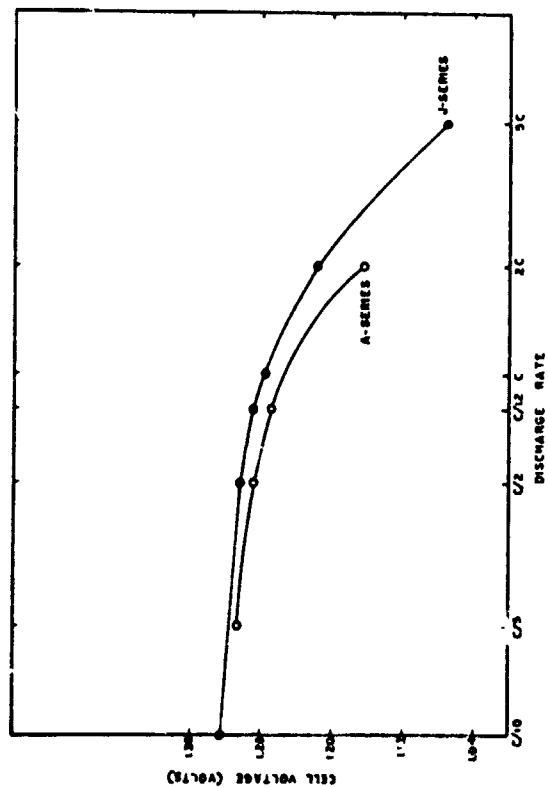


FIGURE 127

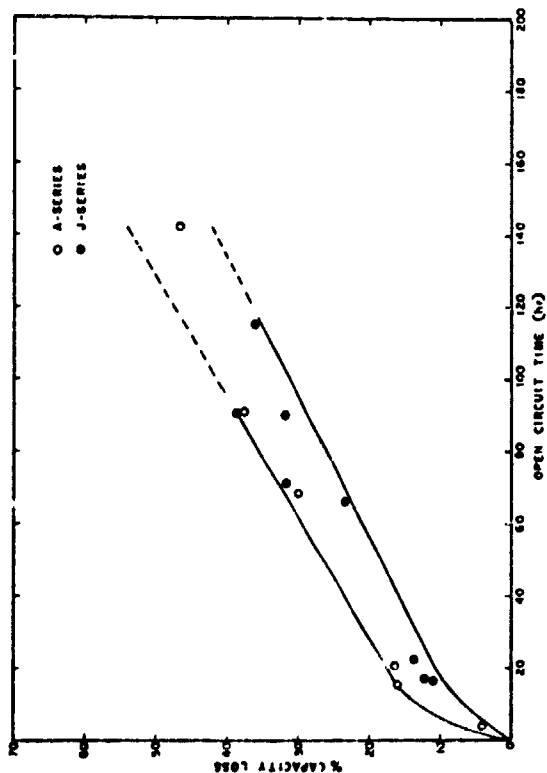


FIGURE 129

	Voltage Efficiency		
	Average Charge Voltage at C/10 Rate (V_c)	Average Discharge Voltage at C-Rate (V_d)	Voltage Efficiency (V_d/V_c)
Ni/H ₂	1.46	1.27	0.87
Ni/Cd	1.41	1.23	0.87
Cd/O ₂	1.75	0.75	~0.43
H ₂ /O ₂	1.70	0.80	~0.47

FIGURE 130

LN12

For the nickel hydrogen and the nickel cadmium cell, it's about 87 percent compared to 43 percent for the cadmium oxygen and about 47 percent for hydrogen oxygen. The difference there is, of course, the inefficiency of the oxygen electrode. This particular aspect could have, under some conditions, an influence on the size of the solar array needed to charge the cell.

Could I have the next slide, please?

(Slide 131.)

We also compared the heat effects of these same systems using standard enthalpy changes. We determined a thermal neutral voltage and from that determined the heat pass during the charge and the heat pass during discharge. In the case of nickel hydrogen and nickel cadmium during charge the reaction is endothermic whereas for cadmium oxygen and hydrogen oxygen there is considerable heat produced.

Then looking at that last column, "The Thermal Ratio," which is the energy which appears as heat compared with the useful electrical energy of the cell on charge, the nickel hydrogen, nickel cadmium show about -2, -3 percent compared with a much larger loss of useful electrical energy for the cadmium oxygen and hydrogen oxygen systems.

With regard to reliability for this system, we would anticipate that it would be a very reliable system. It has only one gas cavity compared to a hydrogen oxygen cell so that the construction is very much simpler. It's not necessary to shield the nickel electrodes from the hydrogen which makes construction simpler and the cell can operate in a wetted condition. Perhaps the main disadvantage of the nickel hydrogen cell compared to the nickel cadmium cell with regard to reliability is the need of storing hydrogen under pressure.

As far as life expectancy or the number of cycles is concerned, if we define the intrinsic life as the life determined by the deterioration of the electrodes, we certainly have two excellent electrodes to work with and the information on the nickel electrode and the hydrogen electrode indicate that these are indeed very long life electrodes.

Another significant advantage of the nickel hydrogen system over and above all of its attractive performance characteristics, overcharge overdischarge protection, is its high fully usable weight energy density. To a first

LN13

approximation, the advantage over the nickel cadmium system for instance can be demonstrated by substituting the weight of some commercial hydrogen electrodes for the weight of the cadmium electrodes and as an approximation the energy density, disregarding the case weights, rises from about 17 watt hours per pound to about 24 watt hours per pound.

Last slide, please.

(Slide132.)

I'd like to summarize what we think are the advantages and disadvantages of the nickel hydrogen system. The first most obvious one there is the energy density per unit weight and what we're anticipating is 25 to 30 watt hours per pound. A significant proportion of that weight -- I think it's about 25 percent, the weight of the whole package -- is the pressure vessel itself. We're currently considering using Inconel. If we could substitute titanium or some other higher strength material, that 25 watt hours per pound would go to about 40 watt hours per pound. The energy density per unit volume since we're containing a gas is probably not the most desirable feature but on a square projection we anticipate about 1.2 watt hours per cubic inch.

Powerdensity and discharge, we have demonstrated 100 watts per pound and also on charge. State of charge detection is certainly unique to this system. Overcharge protection, we have excellent overcharge protection in terms of the rates at which the cell can be overcharged providing that it has adequate heat dissipation. Overdischarge protection, a cell can be reversed without anything catastrophic happening to it and subsequently the cell can be operated without any detriments.

Low temperature performance is then mentioned. We have the Ptolemaic efficiency here on charge compared to a nickel cadmium cell. Reliability, due to the simplicity of construction and the use of one gas cavity. We expect long cycle life based on the separate information on those two electrodes that go to make up the system.

Insensitivity to state of charge storage, I think that it could be stored in the charged or the completely discharged state without damage, unlike, for instance, the lead acid itself which cannot be stored in the discharge state. We also anticipate low maintenance of a completely sealed system.

LN14

Potential disadvantages: the storage of high pressure hydrogen which may be more of a psychological disadvantage than a real one although it has to be demonstrated; a relatively high self-discharge rate which we think we can do something about; and the same problem that you have in the nickel cadmium charge, inefficiency at high temperature.

That's it.

(Applause.)

DUNLOP: Thank you, Larry.

I'd like to bring forth the next speaker now, Marty Klein, from Energy Research Corporation.

KLEIN: Thank you. I think the previous two speakers made a good point that the chemistry looks pretty good for the nickel hydrogen and we have the variety of single electrode cell tests there in this 500 to 1,000 cycle stable performance. I think to translate that into a light-weight cell that delivers 30 watt hours per pound is a little bit of work and I'll talk about some of that perhaps the other people discussed some of the basic chemistry.

Actually, by way of introduction, in Energy Research we're actually looking at the whole family of secondary metal gas batteries and I think we are going to evolve a variety of system, nickel hydrogen, silver hydrogen, zinc oxygen, cadmium oxygen, that are going to be good for different things and depending on the mission you want to look at.

(Slide 133.)

This, by way of introduction, really is the way we see these metal gas systems in their relative capabilities.

Do we have a pointer?

HENNIGAN: No, it fell in between the board there.

KLEIN: Okay, well, anyway, the hydrogen oxygen there's been a lot of work done on it and it's got cycle life problems at this point. Two hundred cycles is pretty good life. Zinc oxygen probably has got the potential of being the highest watt hour per pound system but also has life problems and then the cadmium oxygen nickel hydrogen in the similar watt hour per pound class but the nickel hydrogen looks a lot better in the cycle life and simplicity and that's the one we'll talk about.

ADVANTAGES OF THE Ni/H₂ SYSTEM

1. ENERGY DENSITY PER UNIT WEIGHT
2. ENERGY DENSITY PER UNIT VOLUME
3. POWER DENSITY ON DISCHARGE
4. POWER DENSITY ON CHARGE
5. STATE-OF-CHARGE DETECTION
6. OVERCHARGE PROTECTION
7. OVERDISCHARGE PROTECTION
8. LOW TEMPERATURE PERFORMANCE
9. RELIABILITY
10. LONG CYCLE LIFE
11. INSITIVITY TO STATE-OF-CHARGE STORAGE
12. LOW MAINTENANCE

POTENTIAL DISADVANTAGES

1. STORAGE OF HIGH PRESSURE HYDROGEN
2. RELATIVELY HIGH SELF-DISCHARGE
3. CHARGING INEFFICIENCY AT HIGH TEMPERATURE

FIGURE 132

Thermal Comparison of Rechargeable Battery Systems

System	Enthalpy Change of Cell Reaction (Kcal equiv.)	Voltage of No Heat Transfer $V_{\text{no heat}}$	Heat Passed During Charge** Cal/Ahr	Heat Passed During Discharge Cal/Ahr	Thermal Ratio* $\frac{V_{\text{no heat}} - V_D}{V_D}$	Charge** $\frac{V_C - V_D}{V_D}$
Ni/H ₂	34.90	1.31	-43	+206	19%	-3%
Ni/Cd	33.31	1.44	-26	+181	17%	-2%
Cd/Cd ₂	32.50	1.41	+290	+568	86%	45%
H ₂ /O ₂	34.15	1.48	+188	+585	85%	27%

*Ratio which appears as heat, compared with the useful electrical energy of the cell

**Negative numbers indicate heat is consumed during charge

FIGURE 131

LN15

The silver hydrogen I'll leave for the next speaker but it looks very attractive and is about one and a half times the energy density of nickel hydrogen, I would say, with less cycle life.

Could I have the next slide?

(Slide 134.)

For any one of these metal gas systems, we've taken the packaging approach of putting a stack of little parallel electrodes, circular in type, in a single cylindrical pressure vessel and the system works on the basis of there's a gas diffusion path to the backside of the gas electrode and a separator up there and then the accompanying metal electrode and you'll see this kind of picture referring to any one of those systems.

Could I have the next slide?

And this is just another picture of the same thing.

Could I have the next one?

(Slide 135.)

For the pressure vessel of any one of these systems, we think that's where the problem lies possibly because everybody is concerned about hydrogen leakage plus you want to have the lightweight housing. We've been doing a fair amount of work and actually the major portion of the work comes from our rechargeable hydrogen oxygen work and this is a picture of an electroformed nickel pressure shell of the type that we are planning to use and we actually electroform this on a mandrel and it's an all one-piece construction and then we weld a dome, put the electrostack in here and weld a dome on the bottom.

This particular picture is of a size cylinder that's two and a half inches in diameter and then on the top of it we've got two ceramic metal seals. Can you lower that? There we go.

In the seal feedthrough area, this is also a whole new ballgame now because you want a seal that's going to take, you know, 500,000 psi and cycle through that so you know how much trouble the nickel cadmium people have had making

LN16

insulated feedthroughs just at ambient pressures and we've taken some of that technology but you have to change your geometry. You've got to work in tubular type structures no matter what you make in these high pressure systems and these are some tubular seals that we've had made. It's got nickel fittings on either end and a ceramic sealing. These particular seals will yield at about 2,000 psi.

Could I have the next slide?

(Slide 136.)

Here's a typical polarization curve of nickel hydrogen pretty similar to the other data.

Could I have the next slide?

(Slide 137.)

Here's a life test that we ran on a single electrode, ran out. This data shows 700 cycles. We've run beyond that and see very little change in performance.

Could I have the next slide?

(Slide 138.)

We're now engaged in a program to build 50 ampere hour lightweight cells and this is our first generation base-line design as we see it for a 50 ampere hour cell. We're going to use a three and a half inch diameter cylindrical housing and this is a compromise as the performance people talked about on this size of diameter.

From the weight standpoint, the lowest pressure, smallest diameter cylindrical vessel is the best based on the weight of the vessel and then you compromise back from there and our thinking is to run a pressure range of 100 to 500 psi and using this three and a half inch diameter.

As we see it, the 50 ampere hour cell will come in at about two pounds and yield 30 watt hours per pound based on our componentry.

Could I have the next slide?

(Slide 139.)

This is the interesting weight breakdown as we see it of the components and if you use a high strength pressure

SYSTEM	OPERATING VOLTS	WH/LB	POTENTIAL ACTUAL ENERGY DENSITY (500 PSI) THEOR.	ACHIEVED LIFE	POTENTIAL LIFE
Hydrogen-Oxygen	.88	20-50	.5	3	200-1,000
Zinc-Oxygen	1.30	50-100	1.8	20	200-500
Cadmium-Oxygen	.85	25-43	1.2	20	500-2,000
Nickel-Hydrogen	1.25	25-42	.8	25	1,000-10,000
Silver Oxide-Hydrogen	1.10	35-60	.8	25	500-2,000

FIGURE 133

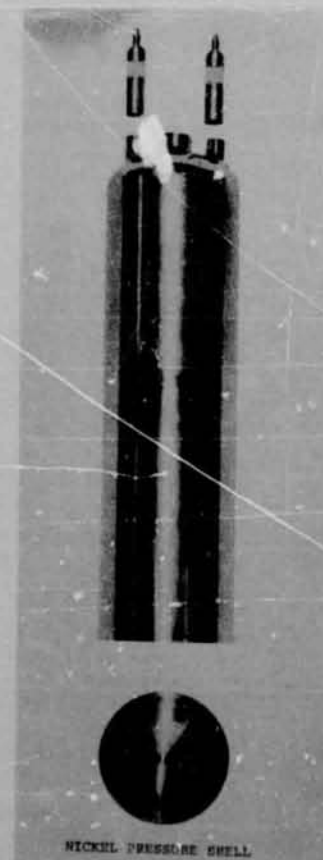
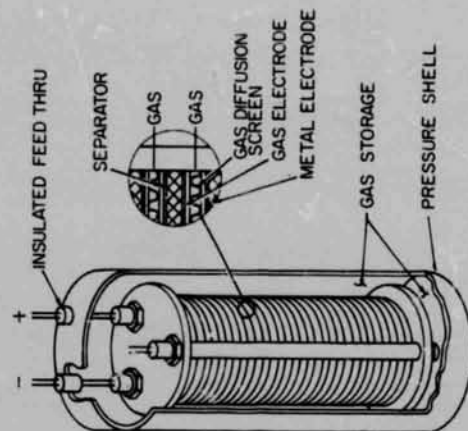


FIGURE 135



METAL-GAS SINGLE CELL CONCEPT

FIGURE 134

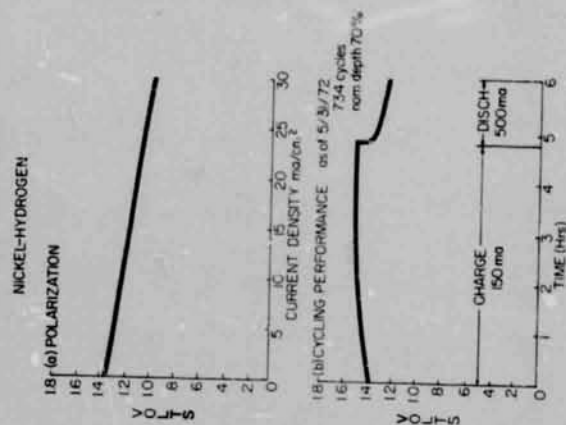


FIGURE 136

ln17

vessel, you're down to the point where the weight of the pressure vessel, the share of the weight of the pressure vessel, is about equivalent to what nickel cadmium people do in prismatic cells and nearly all the weight of the cell or the major share of the weight of the cell is in the nickel electrode and it's there that I think we're going to be doing some things differently.

We have been working for some time in other areas in a non-sintered type pressed nickel electrode that on a weight basis is more attractive than the traditional sintered plaque electrode and we'll be building -- actually all our test results are with this non-sintered type electrode and I would say there's about 35 percent weight saving between the sintered versus a non-sintered type electrode.

There are some questions in the relative life of the two electrodes and there can be some arguments about whether that weight saving really pays off in the end but so far it looks pretty attractive.

The other thing that's kind of important is the weight of your fuel cell electrodes. In this 50 ampere hour cell for real design you've got something like 400 square inches of hydrogen electrode and you've got to really cut the weight out of that hydrogen electrode or you're not going to do too good and this particular number here is based on a very lightweight thin _____ catalyst type electrode that we have developed for some primary fuel cell work and our work now is based on three grams of platinum per square foot loading and that's just because we chose that as a convenient loading.

I think we do want to bring the quantity of platinum down and I would suspect you could probably make nickel hydrogen cells with half a gram platinum per square centimeter-- I mean half a gram per square foot. And we have also looked at non-platinum catalysts and we have some cells that do work a little worse than platinum.

Could I have the next slide?

(Slide 140.)

This is a picture of the electrodes that we're using. It's kind of distorted. This is a 3.1 inch diameter showing the pressed nickel electrode. In the separator area we have also taken a little different attack and we're using a potassium titrate composite that we make ourselves and the

RESULT: 4 ENC NI-H₂ LIFE TEST

As of 7/21/72 - 70 cycles

Notes:

As live Disk 2" Dia.
Wt. 5.3 grams
70% Depth
Theo. Capacity 1.15 AH
Nickel Electrode thickness .05"

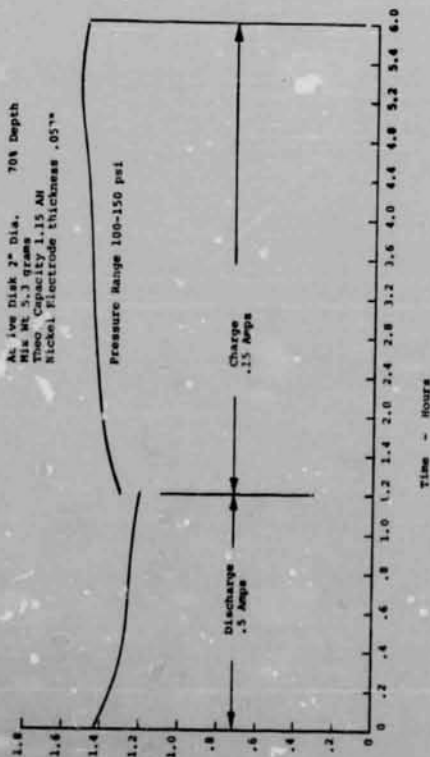
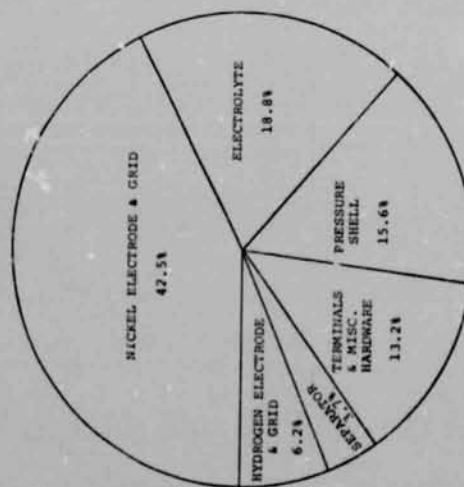
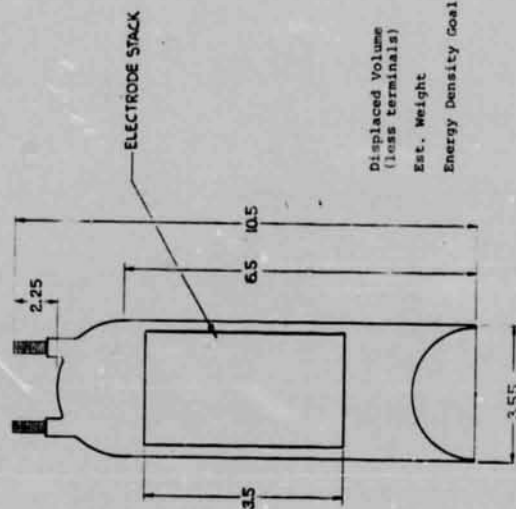


FIGURE 137



NICKEL-HYDROGEN WEIGHT DISTRIBUTION

FIGURE 139



Displaced Volume (loss terminals) 81.5in³
Est. Weight 2.08lbs.
Energy Density Goal 30WH/lb
.8WH/in³

FIGURE 138

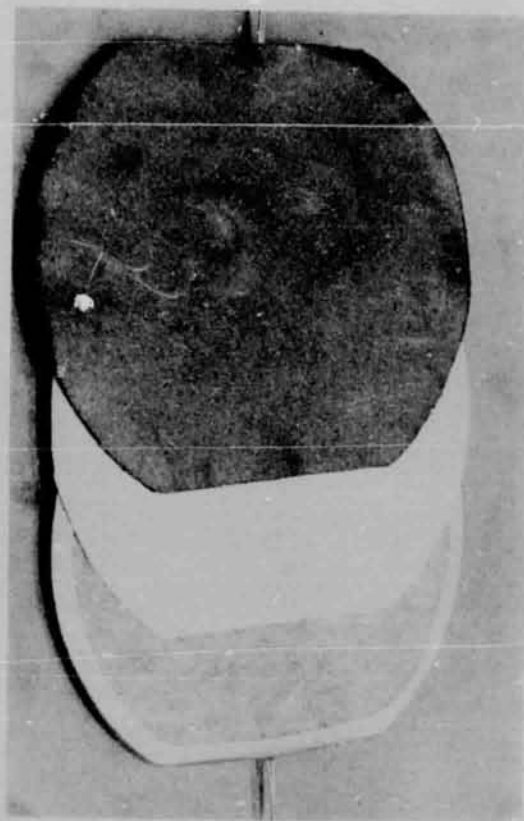


FIGURE 140

ln18

thinking there is that if you start out with an inorganic material like potassium titanate that we know wets because it has a good contact angle with electrolyte and we know it's chemically stable, in the long run we'll be better off so we're using that type of material as opposed to the nonwoven polypropylenes. Here's the hydrogen electrode that I'm talking about.

Could I have the next slide?

(Slide 141.)

This is a photograph of an actual 50 ampere hour test assembly and consists of the sequential layers of the nickel electrodes and hydrogen electrodes and there are actually 28 nickel electrodes in here and what we've done is we've taken wires off each electrode and bent them and brought them out the top.

We are now putting springs on the top of the electrode stack because we feel with 28 electrodes the separator layers and all the hydrogen electrodes, there is this thickness tolerance problem and for the time being we're using a spring-loaded stack to make sure we get sufficient compression in the cell.

Let's see what the next slide shows.

(Slide 142.)

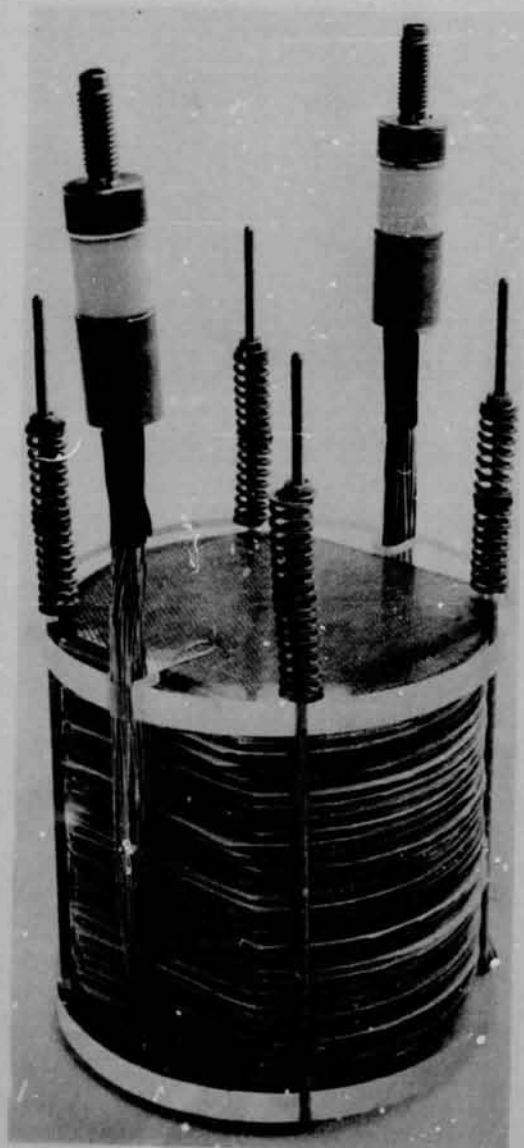
This is an actual polarization curve of this 50 ampere hour prototype. We have not built lightweight 50 ampere hour cells yet. This data is taken in a heavy steel boilerplate type housing. I don't have a slide of the housing but it's a three and a half inch diameter and about six inch. I have a photograph of it but I didn't get a slide of it.

Could I have the next slide?

(Slide 143.)

And this is performance of that same stack over-discharge of 5, 25 and 50 amps and showing we're getting pretty good 50 ampere hour capacity. We have not put this stack on cycle. We're still doing some parametric testing of it and so far it looks pretty good and that's about the status of where we are right now.

(Applause.)



ERC NICKEL-HYDROGEN (50A.H.)

FIGURE 141

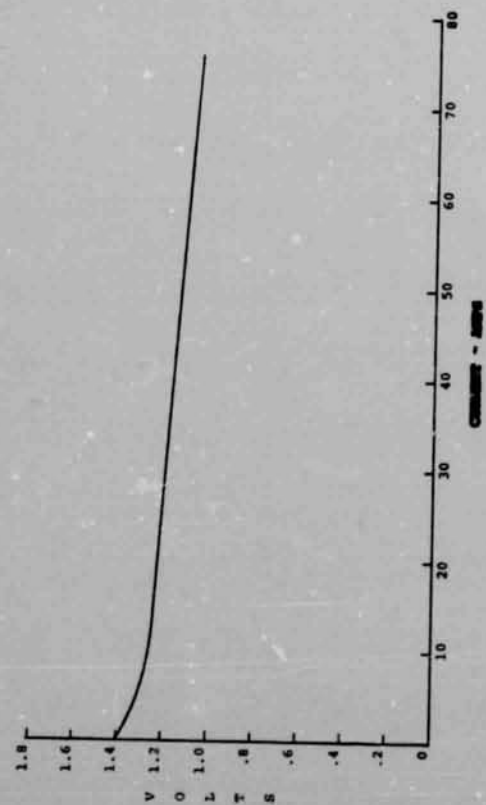


FIGURE 142

ERC NICKEL-HYDROGEN (50A.H.)

Room Temperature

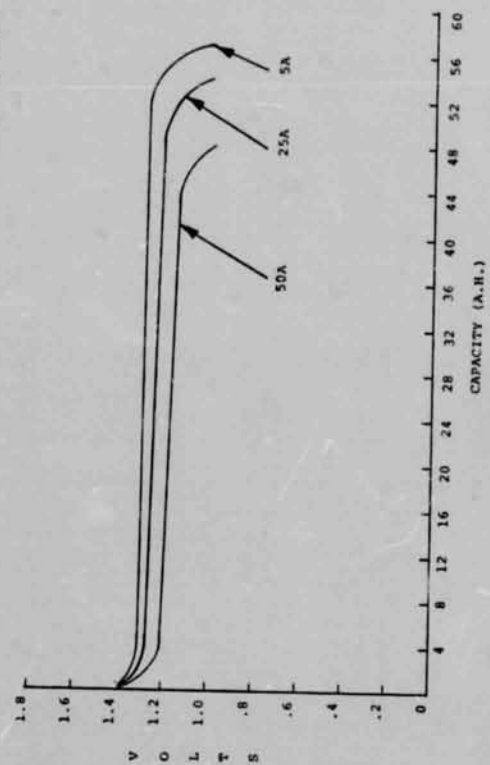


FIGURE 143

ln19

DUNLOP: I want to make one comment before I bring the next speaker up. Marty brought to mind in terms of the sealed technology. We have a 50 ampere hour cell that -- there are a lot of cells that are being made mostly in boilerplate construction right now, but the seals that we're using in the cells that we're running at the lab are using the Ziegler seal and the Ziegler seals were provided to us by courtesy of Bell Labs and we appreciate it.

We've run those seals at pressures up to 1,000 psi of hydrogen with no problems to date and we've temperature cycled them for, I don't know, 100 cycles or so to date with no problems and the plan to continue doing some fairly extensive testing in these boilerplate configurations at this point in time using that Ziegler seal.

The next speaker we have is Mr. Ron Haas of Philco Ford and he is going to describe the work he's doing on the silver hydrogen cell. Ron?

HAAS: Let's see we have a couple of things I want to comment on before we actually start with the slides. Philco is interested as most space companies are in recent years with the weight of the cells, batteries, nickel cad cells and one area that we've focused on in the last year is the silver hydrogen cell. And we have, for those of you who are interested after the presentation or later this afternoon, we have a little foldout, a little folder and a five amp hour cell. This is a white hardware cell and we'll be available for comments.

Okay, let's have the first slide.

(Slide 144.)

Some of the interesting characteristics of a silver cell as opposed to the nickel hydrogen cell is, of course, the ampere hour capacity of the silver electrode and when we have the first slide we'll take a look at that. We're typically thinking of a nickel electrode with grams per ampere hour in the order of, oh, 9 to 10 grams. There are some electrodes, nickel electrodes which might do a little better than that.

The silver electrode for those of you who have worked in the field of silver cells, silver zinc, silver cad, are aware of the grams per ampere hour there -- the grams per ampere hour for the silver electrode are in the order of two and a half to three grams per ampere hour. This is quite

1n20

a difference, of course, as compared to the nickel electrode. We've summarized some of these features, electrical characteristics and some of the mechanical design features which we feel are of interest for a silver hydrogen cell and I think this --

first, of course, the weight of the cell, the energy density that we're able to achieve this is of most interest and we have, as I have shown you, a five ampere hour cell. The energy density on it is 30 watt hours and we would anticipate for larger cells in the order of 20 to 50 amp hour sizes. We would improve on that, of course.

I think our previous speakers have demonstrated quite well the uniformity and the stability of the electrodes which they're using and, of course, the only thing different with the silver hydrogen cell would be the silver electrode. Silver cells with regard to the silver electrode have rather good stability with cycle life.

With regard to cycle life, we feel that a typical synchronous orbit type cycling we expect a cycle life of in the order of 1,000 cycles. We have data which we'll be getting to on the next slide which shows the characteristics after some 600 cycles.

In the area of the mechanical design, we used a standard silver electrode which is used typically on silver zinc cells. The hydrogen electrode is a fuel cell electrode. It is somewhat different than the electrodes which have been discussed thus far and we aren't in a position to reveal the characteristics of the hydrogen electrode. The separator is a capillary mat and it is stable in electrolyte and again it is not similar to the separators which are being used on the nickel hydrogen cells described this afternoon.

We feel that for a single cell we would like to use a vessel which would house just a single cell, not a series of cells within the vessel. This allows us in the evaluation of cells to select cells for a battery assembly.

It is important, we feel, to optimize the thermal characteristics and this particular cell is similar to what we use with a nickel cadmium cell. Future cells would be modified somewhat and they will not look exactly like this but the basic cell geometry would be similar. We're using the gould seals, ceramic -- and let's have the next slide.

(Slide 145.)

LN21

This is a test vessel that we utilized for evaluation of single cell, single electrode cells, and it may be a design which some of you have seen before. Okay, we have a ceramic feedthroughs on the assembly, as you see, a number of them and these are utilized for reference electrodes and to, of course, bring the release for both the positive and the negative electrode.

Let's have the next slide.

(Slide 146.)

This slide shows the cycling characteristics of a single electrode cell. Six hundred cycles we show here. The charge rate as you see is a very high rate. The discharge rate is a very high rate. One of our first thoughts in evaluating silver hydrogen cell or any other new cell is let's find out what the limitations are, what the failure modes are and, sure, we can spend a good deal of time working up to this over a long period of evaluation, but we felt that let's evaluate a cell at a very high rate charge, very high rate discharge. The charge of the cell -- the charge voltage was limited as shown. I think the important thing that we see here is a substantial degradation in the discharge voltage of the cell.

Now, the depth of discharge, as you see, is in the order of about 80 percent of the actual electrode capacity that we obtained originally.

Next slide, please.

(Slide 147.)

After finishing the 600 cycles we obviously had a substantial degradation in the voltage of the cell and we were interested in then characterizing the cell. This would tell us what a silver hydrogen cell should be capable of after five years of operation after 600 cycles; and we have several lines, curves, here. This one is the polarization curve after the 600 cycles. We have other data which has been published and we show -- this is a silver hydrogen cell that was developed by another company and a nickel hydrogen cell and so that we show the comparison in voltage as a function of the current, the density.

The upper curve is a beginning of life curve which was obtained on the five amp hour cell.

SILVER-HYDROGEN CELL

DESIGN AND PERFORMANCE CHARACTERISTICS

ELECTRICAL PERFORMANCE FEATURES

- HIGH ENERGY DENSITY CAPABILITY (30 TO 50 WATT HOURS/POUND)
- EXCELLENT ELECTRODE CAPACITY STABILITY
- UNIFORM VOLTAGE CHARACTERISTICS
- LONG CELL LIFE CAPABILITY
- FAULT PROOF UNDER OVERVOLTAGE "REACTION"
- DISCRETE CHARGE VOLTAGE TERMINATION SIGNAL

MECHANICAL DESIGN FEATURES

- STANDARD LIGHTWEIGHT SILVER ELECTRODES (2.5 - 3.0 gms/AM)
- FUEL CELL HYDROGEN ELECTRODES (3 - 10 mgPt/cm²)
- CHEMICALLY INERT CAPILLARY T/A SEPARATOR
- AUTOMATIC SINGLE CELL CONTAINER
- DUAL CERAMIC SEAL ELECTRICAL CONNECTION
- REDUCED THERMAL GRADIENTS
- INTEGRAL HYDROGEN GAS STORAGE CHAMBER

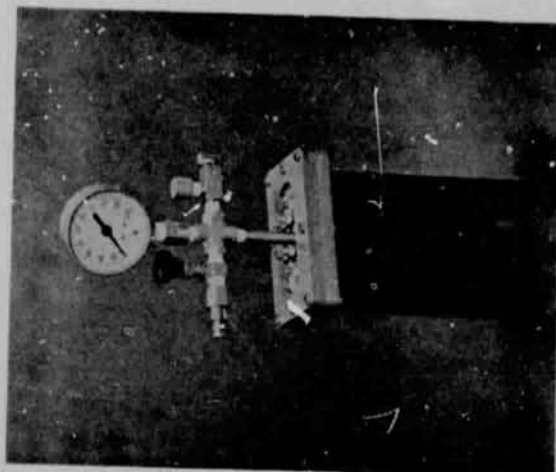


FIGURE 144

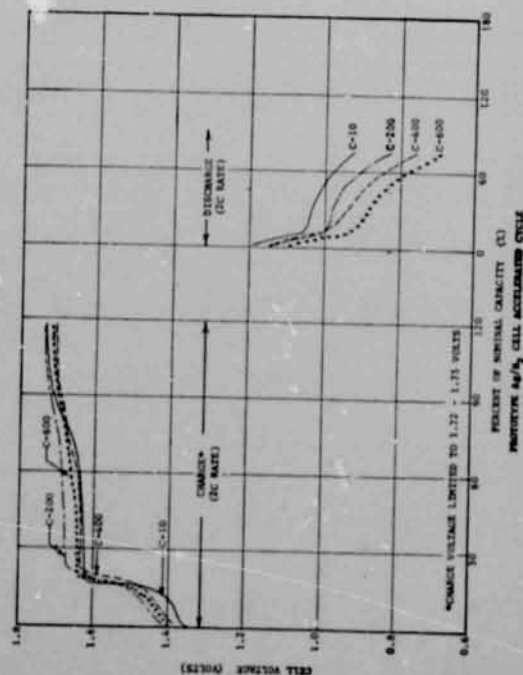


FIGURE 146

FIGURE 145

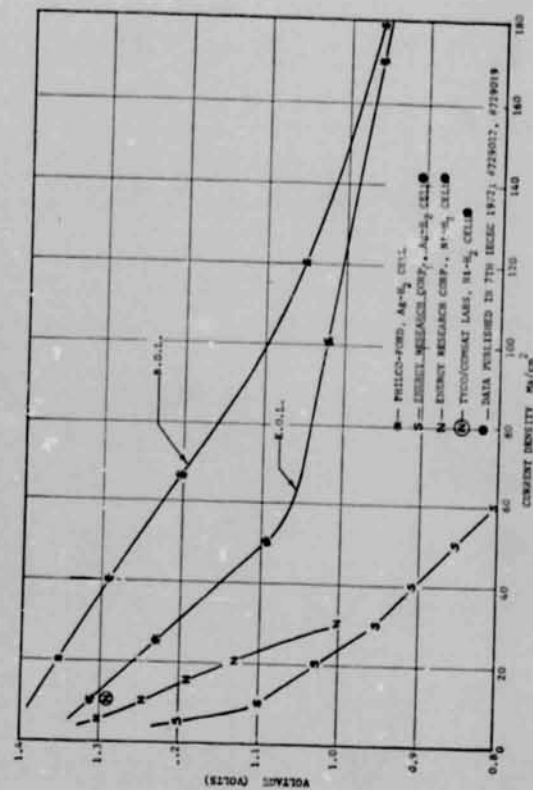


FIGURE 147

COMPARISON OF METAL-HYDROGEN CELL POLARIZATION PERFORMANCE

ln22

Next slide, please.

(Slide 148.)

In an effort to characterize a cell after substantial cycling, we went through a series of charges and discharges at various charge rates. This slide will show the voltage characteristics with our voltage upper limit. The next one will show similar charge/discharge curves without the voltage limit.

(Slide 149.)

We have a swing at the end of charge or at a full state of charge which most of you are probably familiar is characteristic of the silver, the electrode. So it does provide a nice signal for terminating a charge on a cell if it's felt necessary for a particular application.

One interesting point, though, and we don't need to go back to the other slide, but one interesting point we see that with the relatively high rate charge we have a discharge voltage initially which is the silver oxide voltage which is somewhat higher than we have at the lower charge rates. I don't have an explanation for that characteristic at this time.

One limitation that's been noted with the nickel hydrogen cell is the ability to retain charge on open circuit. This curve is our C/10 charge. We then allowed the cell to stand for 72 hours over a weekend and discharges here and you can see that essentially we lost an over capacity which is a feature which could be rather important for certain applications.

Next slide, please.

(Slide 150.)

This is the five amp hour cell. The cell is assembled with a design which is similar to to rectangular electrode design that's utilized on most battery cells. We feel that the rectangular shape is relatively important in reducing thermal gradients. Now, we have reason to believe that if you do not provide adequate thermal control that we can expect temperature swings of, oh, 10 to 15 degrees C and I really don't have a reason to suggest that the operating temperature of a cell shouldn't be 50 C, but we have learned

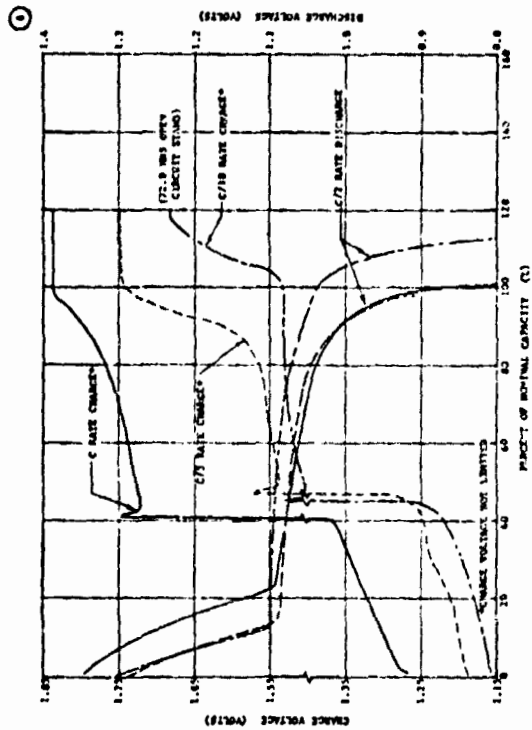


FIGURE 148

92A

FIGURE 149

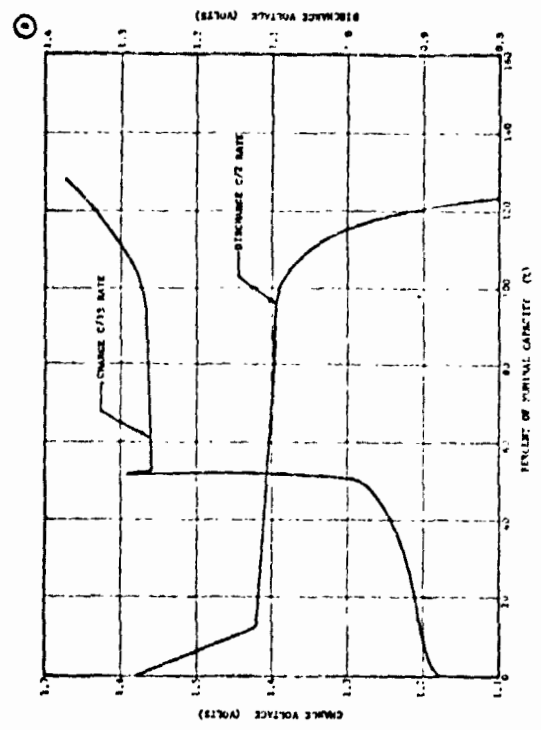
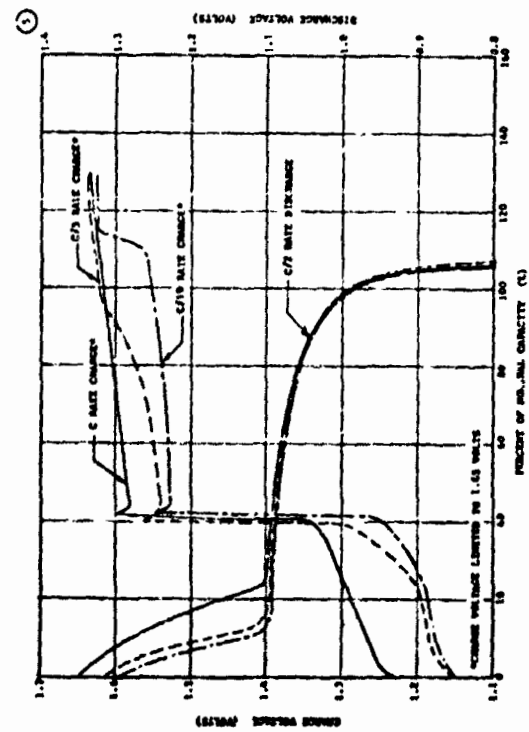


FIGURE 150

DCB-40
S/N 1002
PHILCO
SILVER-HYDROGEN
5.0 AH AT 1.5 AMPS
DATE/ACT 10-20-72
WEIGHT 85.7 GMS

FIGURE 151



In23

in the battery business that we like to keep the cells at a uniform temperature. We don't have data which would indicate this is essential for the silver hydrogen so -- next slide?

(Slide 151.)

This is a typical charge and discharge curve for our five amp hour cell. Incidentally, we rate it at a four. It's at this point in time. Whether it's a four or a five probably isn't awfully significant. The discharge voltage -- incidentally, this is our scale for the discharge -- we're slightly above 1.1 volts. The charge voltage I don't know how we average it but somewhere between 1.45 and 1.50 on the average.

Next slide, please.

(Slide 152.)

This is some of the basic design information on the five amp hour cell. The weight as shown is 68 grams. Now that would be without the seal which is shown on the cell. The weight characteristic is a function of the energy of the cell. It's 295. The geometry is shown.

We have three silver electrodes and six negative electrodes. Each silver electrode has a hydrogen electrode on each side of it and we're using a stainless case and cover and ceramic seals.

Next slide, please.

(Slide 153.)

We've summarized the energy density capability of various cells. Now, this would be a battery, typically a 20 cell battery assembled in a package which would be of plate quality and I think we're all familiar with the capability of our typical nickel cadmium battery. Nickel hydrogen, I think they this afternoon fairly well depicted what the capabilities are. We show a maximum there of about 30 watt hours per pound.

Silver hydrogen, we have a datapoint on a white hardware type silver hydrogen cell which we show here. There is a packaging factor involved and if we then swing it up somewhere between a 40 and 50 amp hour cell we expect that the energy density is shown at about 45 watt hours.

PHILCO-FORD CORPORATION
WDL DIVISION

DCB-40
Ag-H₂ CELL

DESIGN SPECIFICATION

NOMINAL CAPACITY: 4.0 AMPERE HOURS
 ACTUAL CAPACITY: 5.0 AMPERE HOURS
 DISCHARGE VOLTAGE: 1.35 - 1.10 VOLTS
 CELL WEIGHT: 85.7 GRAMS
 SPECIFIC ENERGY DENSITY: 29.5 WATT HOURS/POUND
 DIMENSIONS: LENGTH: 2.10 INCHES
 WIDTH: 0.83 INCH
 HEIGHT: 2.08 INCHES
 NUMBER OF POSITIVE ELECTRODES: 3
 NUMBER OF NEGATIVE ELECTRODES: 6
 CASE AND COVER MATERIAL: 304L STAINLESS STEEL
 TERMINAL CONSTRUCTION: DUAL METAL TO CERAMIC SEALS

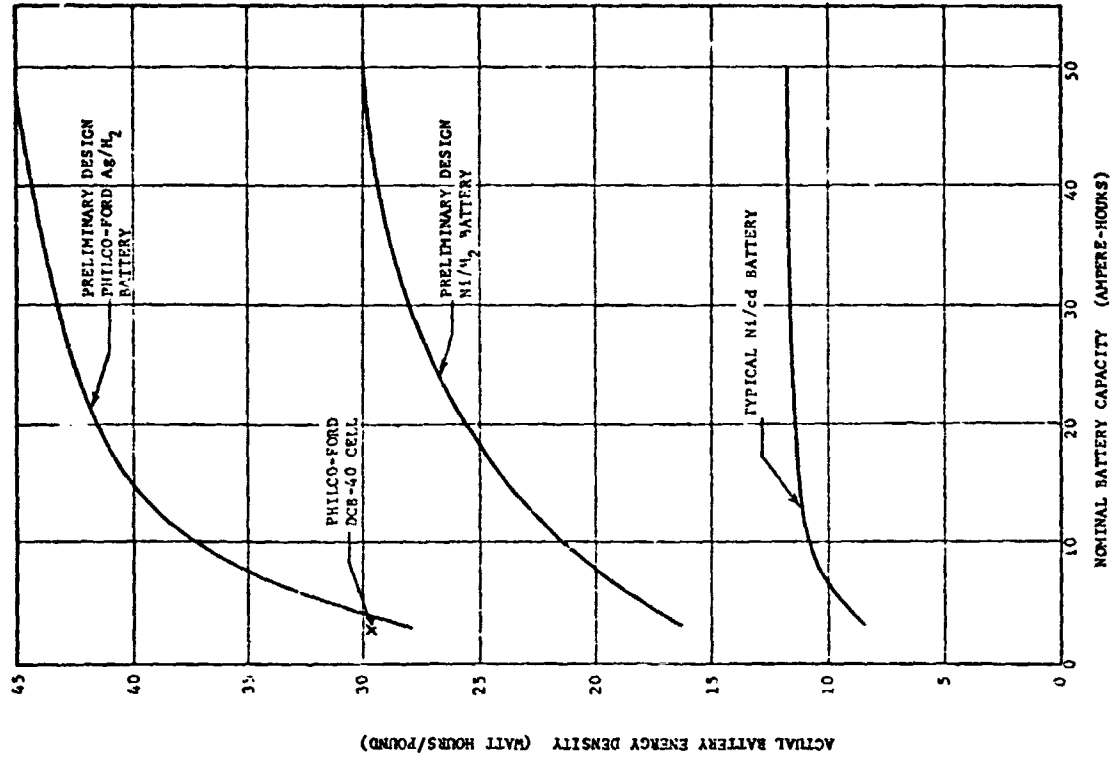


FIGURE 152

FIGURE 153

ln24

I think that's it.

Are we going to have some questions now?

DUNLOP: Yes.

(Applause.)

DUNLOP: Thank you very much, Ron.

I'm going to ask the other two speakers to come up that were here. I want to make a comment -- would the other speakers come up? We'll have a general question and answer session. I want to make a point here that the work that's being reported here or the work that's reported here by Marty and Lou and Ron, Marty and Lou and the work I reported is primarily Intersat supported. I think a lot of this work is actually supported in house. You're obviously talking about a relatively new technology here. It's a very competitive situation at this point in time. Your questions should be directed at these gentlemen with that in mind.

KLEIN: Could we ask each other questions first?

(Laughter.)

DUNLOP: Yes. This is an interesting situation.

KLEIN: I just had a couple of questions, quickies. What's the operating pressure range in that little cell you have?

HAAS: I have to admit we had designed that cell as a three amp hour cell and it turned out that it was about a five amp hour cell and the operating pressure range that we anticipate for synchronous orbit cycling in the future would be in the order of 200 to 300 psi.

KLEIN: You mean the upper limit?

HAAS: That is the maximum pressure that we plan to operate the cell at.

KLEIN: All right. That little cell that you had which gave 30 watt hours per pound, what pressure did you run that to to get 30 watt hours per pound.

HAAS: That was run in an assembly which did not allow the pressure to go above 300. Okay, so that that assembly

ln25

had an auxiliary storage which allowed us to measure the five ampere hours but in synchronous orbit with a depth of discharge at 60 to 70 percent. We see no need for a package which can withstand 500 psi and if we can operate with a package at maximum of 300 psi.

This is a subtlety, sure.

KLEIN: It certainly is.

DUNLOP: This is an area that we're all very interested in and it's very competitive at this point.

PALANDATI: Charles Palandati, Goddard Space Flight Center, I'd like to direct my questioning to Ron Haas. I have two questions, Ron: One, do you have any idea what the contributing factor was with regards to the voltage degradation and the second is do you have any feel with regards to overcharging, is the silver hydrogen system capable of the overcharging that we showed on the other presentations in regards to the nickel hydrogen system.

HAAS: The answer is yes.

(Laughter.)

PALANDATI: To what?

HAAS: Yes, we have operated the cell in overcharge at relatively high rates, C rate and above. The pressure stabilizes similar to the data that's been shown us this afternoon. We see no difference.

PALANDATI: You say you ran at high C rates. What percentage of overcharge are you talking about now?

HAAS: We're talking about the silver electrode being fully charged.

PALANDATI: Yes, but what I'm saying is did you run to a 20 percent overcharge?

HAAS: No, in magnitude let's say it was several thousand percent overcharge.

PALANDATI: Okay, and what about the voltage degradation?

HAAS: The voltage degradation, okay, we were

dh fol ln
dhl

discharging and charging at very high rates. This was a one half amp hour cell, and were charging and discharging at one amp.

There are some standard reasons, like silver electrode degradation, we inspected the silver electrode after finishing the series of tests, and then there was some obvious physical changes on the silver electrode.

PALANDATI: In other words, then you feel that the degradation was definitely in the silver electrode as such?

HAAS: That was a primary --

PALANDATI: And not in the hydrogen?

HAAS: It's awfully hard to believe that there's degradation in a hydrogen electrode, based on the oxygen-hydrogen fuel cell work that's been done.

PALANDATI: All right. Let me ask one other question. I don't want to tie up this meeting here by myself, but did you notice any pressure changes in the hydrogen electrode that could possibly -- why did you suddenly say definitely it was the silver electrode?

HAAS: Well, I'm indicating that the silver electrode had physical changes which would indicate there was a substantial change in the physical characteristics of the electrode.

Now, I'd like to point out in that regard that the silver electrodes we're using are not necessarily designed for this purpose. They're -- as a matter of fact, the electrodes which someone happens to have available, and so I don't feel that that problem would necessarily be characteristic of the cell we would be evaluating in the next year or two.

DUNLOP: Okay. Dr. Seiger.

SEIGER: First question to ron Haas. Is there a hydrogen precharge in the silver hydrogen?

HAAS: We have operated this cell both with some additional hydrogen initially, and without. We haven't seen any benefit, at this point, in the addition of hydrogen, so to answer your question --

dh2

SEIGER: Is that for overdischarged?

HAAS: Yes, that's for the overdischarge.

SEIGER: Good. Now that goes to my second question, and since Marty is sitting up there, why do you have to put in 100 PSI of hydrogen precharge? Can't you get away with less?

KLEIN: Yes. The reason I think 100 makes sense is that if you start looking at the leakage rate, and if you look at a seven year mission, and you want to leak some hydrogen, because you're going to leak it, the more you put in, the better off you are. And I just, you know, said 100 sounds nice.

You can back that out into a cc's per second of hydrogen. It's actually a pretty large number when you do that if you allow yourself to lose like 80 PSI over 70.

SEIGER: Understandable. I've dealt with those kinds of calculations.

DUNLOP: There are two things you do. When you do a computer analysis on these cells -- and you realize when I'm talking about computer analysis, we've all done our own computer analysis. But the results generally agree, and that is that if you optimize for energy density on these nickel-hydrogen cells, and I don't know what the silver hydrogen would be, but on the nickel hydrogen, the optimum pressure range turns out to be something around 300 to 400 to 500, in that order; around 400. A Delta P of 400 is a good number for optimum energy density.

And there's a different number if you want to optimize on volume, which goes to a higher pressure. And so, really basically what you get into is a question, and there's not really much -- however, it turns out that when you design a pressure vessel that contained that 400 or 500 PSI, the difference in the thickness that you designed for, to contain 500 or 400 is a relatively insignificant factor. Almost completely. So you really, you really have a safety factor of 2 or 3, for most of the materials that we're talking about.

SEIGER: I have another question. the Tyco slide, there was a reduction of the pressure during the continuous overcharge, and I was wondering if there's an explanation for that.

dh3

DUNLOP: You might want to answer that, Larry.

SWETTE: I don't know that I can. I suppose one thing that could be happening is a continuing recombination of oxygen, generated on overcharge, if --

DUNLOP: Well, EV is also equal to NRT. And your temperature's gone up.

SWETTE: The pressure was going down in that --

(Inaudible comment.)

DUNLOP: Yes.

SWETTE: The only thing I can think of is more recombination occurring, or a faster rate --

SEIGER: Wasn't there a temperature rise?

DUNLOP: No.

(Inaudible remark.)

DUNLOP: No, there was a slight temperature decrease.

FORD: Let's don't get a private conversation going here.

SWETTE: Oh, pressure decrease. Were you asking about temperature or pressure?

SEIGER: Pressure.

SWETTE: Yes, there was a pressure decrease, and possibly the recombination is more efficient, it's faster --

DUNLOP: Well, I don't think you want to get into that, because there isn't that much partial pressure on the cell. That'll be a different argument.

GINER: One of the things that we have seen is that there is this chemically evolved oxygen in the nickel _____. And this chemical oxygen is consumed, and when that it consumed, it consumes hydrogen, so the hydrogen pressure was down.

DUNLOP: Yes. There is an absorption phenomena

dh4

here.

SCOTT: Scott, TRW. Jim, I believe you were the one that said that it starts to look like the positive electrode, the nickel electrode is now becoming your limiting electrode in nickel-hydrogen cells. Do you know what mechanism is operating there in that respect?

DUNLOP: Well, what we've seen to date, and the thing that we are looking at is the electrodes that we've supplied by, or obtained from different manufacturers, and that includes the ERC electrode, it includes the Tyco electrodes, it includes the SAF electrodes, the GE electrodes, and the Eagle-Picher electrodes.

We're seeing a change in the physical dimensions of these electrodes after a thousand or two thousand cycles. The one thing that we don't know is whether that's related to overcharge or cycling. And I've talked to a couple of people about it, and we also don't know the effect of temperature. But all the electrodes seem to change their structural -- their configuration.

What we are starting now is a high rate test where we're going to run about 1,000 cycles a month on these different electrodes, and we're going to minimize the overcharge by using a pressure switch. And we'll know about six months from now whether that -- when those electrodes start crumbling whether it's due to -- and we're running deep depths of discharge, so we're going to know whether it's due to say a perforated steel or a particular type of impregnation process, or heavier loading, et cetera. These are, you know, have quite a few variables here.

SCOTT: Regarding the silver hydrogen cell, is there not a potential silver migration and shorting failure mode possible?

DUNLOP: Oh, yes. As a matter of fact, to put the whole silver argument in perspective, and this is not, this is the kind of argument we generally get into.

Now if you talk about a 2 kilowatt application, for example, -- there's two numbers you look at here. You look at energy density numbers, but then you really talk about the weight that you're talking about in your system. If you take an Intelsat V or something like this that would not be 2 kilowatts, your battery might weigh 500 pounds, 400 pounds, if it were nickel-cadmium. It would weight something like maybe 100 to 200 pounds if it were nickel-hydrogen.

dh5

So your weight saving would be 200 to 300 pounds. If you went to silver hydrogen, you probably would save another 50 pounds.

GROSS: Sid Gross. I'd like to get this tank weight problem clarified. The energy research tank was relatively light -- only 16 percent of the total package. Does that agree reasonably well with the Tyco tank concept?

DUNLOP: The Tyco -- we are in a competitive situation here, between two contractors. But Tyco is using Inca now, and both of them are using about the same ratio of safety factor, --

GROSS: Roughly what? What kind of number?

DUNLOP: 1.5 -- 2. I think there are other materials that are being looked at as well that have some significant advantage. But as Lou pointed out, in his cell, it was about 25 percent -- that's a 50 ampere hour design, this is what he said. 25 percent of the weight was in the container, and Marty Klein said about 20 percent, 19 or 20 percent in this. There's a variation from -- there's a whole lot of other things that vary that.

It turns out that they're using different electrodes and different separators and so forth, so it's not a straight one to one relationship. One person is using one type of separator, another person is using another. So you can't make a direct relationship within one item between the two individuals.

GROSS: I think it's seldom you can get away with a 1.5 safety factor on tank.

DUNLOP: That's probably right, Sid. Maybe it ought to be 2.

STEINHAUER: I have two questions. First, to Marty, since you're working in several metal-air systems, which one are you betting --

KLEIN: Gas.

STEINHAUER: Gas-air, rather.

Which one are you betting on at the moment, or what looks best of the four that you've described previously?

KLEIN: It has to do with what you want the battery

dh6

to do. There's no "best." If you want the highest watt hour per pound at a couple hundred cycles, zinc-oxygen is the best. If you want the longest cycle life at 30 watt hours per pound, nickel-hydrogen's the best. There's no answer.

HALPERT: Who's going to say something about the migration?

HAAS: Yes, there have been some questions. We've discussed the silver-hydrogen cell, and what some of the limitations are. In an effort to determine what the limiting cycle life might be, we've run, as you pointed out, the 600 some cycles at a very high rate.

Now, what can we do to extrapolate that into C/15 charge, a relatively low rate discharge, in terms of cycle life and time. I'm not certain, but I think it's reasonable to assume that we can go 1,000, 1500 cycles -- it's certainly a function of the time.

And my comment on the physical appearance of our separator after this cycling. Because the separator was definitely a gray color. It would appear that there was some silver movement within the separator. You saw the results of the 72 hour open circuit, which followed the 600 some cycles, and based on that, we don't feel we had a short which was -- that we could observe.

STEINHAUER: With regard to the tankage problem, I think the Tyco people referred to the possible multiple cells in one tank. Has anything been done with regard to optimizing that tank pressure? Could you operate at several thousand PSI to some advantage?

GINER: We have looked at that on paper. But we have not made an experiment of 1,000 PSI or something like that.

I brought here a little bomb. I can assure you that it's very difficult to fly this vase on a plane with something like that.

(Laughter.)

VOICE: How did you bring it down?

GINER: Didn't look. Anyway, that is a typical 25 amp hour configuration at 600 PSI with about 100 PSI base

dh7

pressure. The diameter is four inches, and it has two Bell Telephone Laboratories type seals, Zeigler and Polymeric seals. And there are many ways of making the cell.

Now with this here, you come to an energy of 22 watt hours per pound for 25 amp hours. If you slightly increase, like that, you get about 50 amp hours with about 28 watts-hours per pound. If you change the case, you gain additional -- you can go up to 40.

You can also change the diameter of the case, and get a little improvement. One thing that we think that is necessary, however, is to have a cylindrical or a spherical cell. I don't understand how you can operate this square cell at these pressures. Unless you get a very thick wall, and then of course, your energy density goes down.

HAAS: We don't operate at 600 PSI.

GINER: Yea, but even if you go to the optimum when you go let's say 400, 300, I don't think that you can do that with a square cell.

The other point is regarding the heat rejection problem. We think that's a cylindrical configuration of the right form with the stack electrodes. It doesn't have a heat rejection problem; you can minimize that. Anyway, not with a square configuration.

BOGNER: Bogner, JPL. What was your separator system, Ron?

HAAS: I indicated that this was not the same as the separator systems that were described. We really aren't in a position to discuss it.

VOICE: Is that proprietary?

HAAS: No, I didn't say that.

(Laughter.)

RAMPEL: Rampel, General Electric. I would like to ask this question of the nickel-hydrogen people: Have any of you noticed any memory during cycling from the nickel electrode?

DUNLOP: Okay. The answer is, well, the nickel electrode seems to exhibit the same type of reconditioning

dh8

effect that you see in a nickel-cad cell. If you're using a SAF-type, or GE, or any of them, any of the centered electrodes, in other words, you have the same type of voltage degradation, and you completely discharge it, and you get a subsequent improvement in the voltage in the next cycle. It's the same exact phenomena that you observe with a nickel-cad cell.

SULKES: Sulkes, ECOM. This is in regard to the silver-hydrogen. I notice you didn't present any low temperature data. Is this due to perhaps the fact that in order to cut down silver migration, you're using more concentrated electrolytes?

HAAS: No it isn't. The KOH _____ concentration that we used is a typical; it was not high. The operating temperature here was in the order of 20 degrees C. We haven't looked at -- oh, either low temperature or high temperature operating characteristics at this point.

GINER: I want to make -- I think that regarding nickel-hydrogen cells, we see an advantage for the system when you want to have very, very high rates like 50 C. or something like that. The rates that are practical for satellite operation, and even higher than that to the 5 C., the 12 minute discharge, the nickel-hydrogen worked very well.

HENNIGAN: I'd just like to make a comment here on this silver-hydrogen one, where several years ago, we looked at this calcium hydroxide coating on the silver electrode, and we didn't follow through too much, but some of our results showed that -- oh, like over 50 cycles, we cut down the migration by 90 percent if we measured the pickup in cellophane.

So this might be useful in the work you guys are doing here. Now there seems to be a problem with these things at low temperature, zero degrees, but silver-cadmium cells don't work well at that temperature, anyway, so I don't know if it's the cold or the cells at that time.

FORD: I saw a slide that said one of the advantages of the nickel-hydrogen system is low temperature operation. However, I don't remember seeing any data or any indication of what that low temperature operational point is. Does anybody care to comment on that?

DUNLOP: Yes. We ran charts -- I think I just

dh9

mentioned it, Floyd, we didn't -- there was no data shown here. The cells have been run down to minus 12 degrees Centigrade. We have run them continuously, cycled them, at 0 degrees Centigrade, at C/3 continuous overcharge for 60 percent, 70 percent depth of discharge, and we've done that for, I don't know, maybe -- a cell that was running for 700 cycles, we then ran another 100 cycles or 200 cycles at 0 degrees Centigrade.

And I think it's still running at 0 degrees Centigrade. Is that right? What's it doing now?

SWETTE: We've operated a few cycles at 0 degrees Centigrade, and the cell performs quite well. It does suffer more polarization, as you would expect, but the charging efficiency is better, and the charge retention is also better, at 0 degrees.

GINER: We expect that in low temperatures, you don't have the limitation with the negative electrodes, even up to the point where the KOH starts freezing. That is the experience we have had in separator type experiments. At what moment the positive electrode starts deteriorating, we don't know.

DUNLOP: Well, we started to see loss in voltage down around minus 12 degrees Centigrade. Loss in capacity. Loss in voltage performance. Well, I think that's probably due to the positive.

But I'm not absolutely sure of that, Hose, and I really think we're in kind of a touchy area here, because we were trying to check which electrode was causing the problem, and I'm not sure you don't get some polarization lossage at the hydrogen electrode, as you get into lower temperatures on discharge.

SCHULMAN: Schulman, Gulton. I'd like to direct this question to the nickel-hydrogen people. What are the highest pulse rates on discharge they have attempted, and what sort of voltage levels do they find?

GINER: We have attempted a 5 C. discharge. That is 12 minutes.

SCHULMAN: What sort of voltage levels do you see at the 5 C. discharge rate?

SWETTE: Let's see. That's 5 C. The mid-discharge

dh10

voltage is about 1.06 volts, and the midcharge voltage, as I recall, was about 1.7 volts at the 5 C. rate.

SCHULMAN: Have you any feeling about what would happen if you went to the 20 C. discharge rate?

SWETTE: I guess it would heat up a little bit.

(Laughter.)

GINER: We think it can be done because the nickel-cadmium does it, the nickel-hydrogen does it better. And that was for an aircraft starting battery, you would want these very high things. And the hydrogen is loafing in this type of operation. A hydrogen-oxygen fuel cell can operate on top of 5,000 amps per square foot, and we're operating here the 5 C. rate, about 100 amperes per square foot.

So, the potential for the negative electrode is enormous.

STEINHAEUER: It seems that this nickel-hydrogen development has come to fairly rapid, optimum type results in a short time, compared to hydrogen-oxygen. The cycles you're showing are good for synchronous; yet to be proven for low earth.

I guess in light of this optimism, I'd like to ask either Goddard, or Air Force, are any flight experiments in the planning?

VOICE: Hear, hear.

FORD: That depends on what you call "plans."

I will say that my assessment is that I've heard comments around today that, well, will this really replace the nickel-cadmium. And I'm not going to stand here and say that today, and say it will. I think there are certain applications that it looks highly desirable, that it could replace it. And it is one of the few systems that I've seen in the last five years, that it has the highest potential of replacing it, and we are definitely interested in this for synchronous orbit, but even moreso, an application of low earth orbit.

And we are planning to pursue that. Does that answer your question?

dh11

BENE: Benny, NASA/Langley. I've got a question for Marty Klein. The separator system you're using, potassium-titinate. What type of structure does that have?

KLEIN: Well, it's a Teflon-bonded potassium titinate. I don't know if you're familiar with it. Potassium titinate comes as a pigment. I guess -- it's a fiber, but I think the diameter is a tenth of a micron, and the length is a couple of microns, and we make that into a sheet that's about 75 percent porous, and the average pore size is -- I don't know. Pretty small.

But it's more of a mat type material rather than these open mesh type polypropylenes.

DUNLOP: You might mention how that was developed.

KLEIN: Yea, that's an outgrowth of the regenerative fuel cell. A lot of the material technology here is obviously an outgrowth of regenerative fuel cell work; the pressure vessel, the hydrogen electrode, and even this potassium titinate work.

GINER: I would like to make a point to that, and obviously, in the nickel-hydrogen, you don't need an impervious separator. And we are using, at the moment, at least -- we are using polypropylene without any problem, and I think that the difference between -- Marty, in our work, is that we're using different technology regarding the positive electrode.

We don't see, for instance, a need with the sinter electrode to use these springs to keep the pack from expanding and contracting. Now, you know the fact that if you used pressed electrodes makes also, forces you to use an inorganic separator.

KLEIN: I don't know, really. We just chose, right off the bat. That's the material we were making; we had, and I knew its characteristics, and I knew it was very stable in that kind of environment. That's what we started to work with.

GINER: It has the definite advantage of temperature. In other words, because it's inorganic, for instance, you can --

KLEIN: I don't know. I mean, we listened all day yesterday to the pros and cons of polypropylene, I had something I knew, and I stuck with it.

dh12

DUNLOP: Well, I'll make a comment that this is a tough area we're into now. Certainly, both of these systems, the pressed electrode with potassium titanate and the sinter electrodes with the Hercules, polypropylene separators, both those systems have demonstrated over a thousand cycles of operation with no problems in the electrolyte mesh. Both those two systems work.

Now, the thing I want to avoid here is, you're talking about a lot of different combinations, and we haven't even started to talk about other combinations of hydrogen electrodes yet.

So, you don't solve all of the problems. What we really, basically said here to date is that we know if we take conventional stuff that's available, that's conventional SAFT or anybody else's sintered electrodes, or Marty's pressed electrode, and a combination -- we can put it together and we can make it work.

Now there are a lot of ways to optimize this system that are second order effects, which we are just beginning to look at. But I think the point that somebody brought up here a little bit ago was a very good one. We would like to get this into something where we could demonstrate it, because it does have some real potential.

It has two big potentials for a synchronous cell. And its cycle life potential as well as energy density potentials, and it's very surprising when you buy both of these things in a new development. A significant energy density advantage, along with the potential significant cycle life advantage, and then all these other things that are sort of advantages in regard charge control and overcharging and state of charge indicator, those are benefits. The reversal capability is a benefit.

So there are a lot of things that look very good about this cell at the moment.

GROSS: For --

DUNLOP: Floyd, you do have some other people that want to talk.

dh13

GROSS: For close earth orbit applications, we want many cycles. Probably a pressed nickel electrode wouldn't be adequate; you might be interested in thinking more seriously about the conventional sintered nickel electrode for this kind of application, what kind of energy density be projected?

DUNLOP: For which?

GROSS: The nickel-hydrogen.

DUNLOP: Well, we -- if you're talking about a six month application, or you're talking -- it depends -- the question is how good the nickel electrode is. That's really what it comes down to. And it's really a question that the limitation is, can you discharge it 70 percent, and operate it for 6,000 cycles, and the point that I made earlier is we're running that test right now with different electrode structures, and we're minimizing the overcharge, because the question about that test is, is it an overcharge, or is it a depth of discharge which kills that nickel electrode, and I guess people don't really know the answer to that question right now.

GINER: Yes, but the question, I think, was, when you substitute the pressed electrode by the sinter electrode, the energy density goes down, or you assume that it goes down. I think that will change.

KLEIN: I'll differ. I would say my numbers show about a 5 watt hour per pound differential.

GINER: If we can get 30 watts-hour per pound, with the sintered plates.

DUNLOP: We don't think there's much difference.

(Laughter.)

WEBSTER: Jim, what have you done with studying charge efficiency? You say this cell is self-discharging, --

DUNLOP: Somebody said that, but that was over two days. It took two days. And see, if you're talking about a one hour rate, it's a negligible effect. You're talking about something that's very -- it's not much different than the nickel-cadmium.

dh14

WEBSTER: I thought you said it lost 50 percent in a week.

DUNLOP: Yes, but I think that's what -- I'm not sure what that cell lost in a week. It might have been 50 percent in a week, but even if it is 50 percent in a week, that's still -- that's like 10 percent in a day. That's 100 percent in an hour. At the C/100 rate, and it's a negligible thing, it's a negligible effect in terms of charge efficiency.

The self-discharge in a nickel-cad cell's about C/100, roughly.

FORD: We have a couple more short presentations we'd like to follow up with, realizing that some people have to leave because of flights and this type of thing, but I think the next ones will be interested.

Next paper I have is by Gene Stroup, and it's on the radio astronomy explorer satellite battery.

Gene.

STROUP: Let me have the first slide there, please.

(Slide 154.)

The radio astronomy explorer satellite was launched into a three hour orbit, three hour and 45 minute earth orbit, on the fourth day of July, 1968. It is still operational; it's mission is the making of very low frequency, radio astronomy studies, from without the earth's atmosphere. The satellite is oriented with respect to the earth by gravity gradient stabilization.

Next slide, please, Jerry.

(Slide 155.)

There are two, 315 foot damper booms extended in opposite directions, for a total span of 630 feet. There are four retractible antenna booms, each extending 750 feet, forming an array in the shape of an X, which measures 1500 feet between extremities.

dh15

(Slide 156.)

The battery consists of a single package of twelve series-connected 6 ampere hour hermetically sealed, center plate, Gulton-manufactured alkaline cells. There are ceramic to metal bushings around each terminal. The cans are deep-drawn, stainless steel with heliarc welded closures. The plates are separated with non-woven nylon.

Eleven of the cells are improved versions of the nickel-cadmium type first flown on the international satellite Aerial 1, at a depth of discharge of 2 percent.

The twelfth cell is cadmium-cadmium, which is referred to as a Coulometer, and is manufactured in accordance with NASA/Goddard patent 3463673, dated August 26, 1969. The Coulometer is made of the same materials as the nickel-cadmium cell, substituting a negative electrode stack for the positive electrode stack, and doubling up on the amount of separator materials, then flooding with electrolyte.

Life tests have indicated that the Coulometer is equal to, and better, than its nickel-cadmium counterpart. The Coulometer should be made of the materials contained in the nickel-cadmium cell with which it is to operate. The Coulometer measures the ampere seconds of discharge during which time the positively connected electrode is being reduced, and the negative-connected electrode is being oxidized.

And no voltage signal of less than 60 millivolts is observed during this charge and charge. While charging, the positively connected electrode is oxidized, and the negative is being reduced with a null volts of less than 50 millivolts, until the positive is polarized, sending the voltage up towards the gassing potential, 1.45 volts.

In the RAE battery, a semiconductor junction is across the kilometer, bypassing the current when the voltage arises to 500 millivolts. A shimmy resistor is placed in the bypass circuit to limit the trickle charge current to C/30, or about 200 milliamperes.

The performance of the Coulometer and battery have been flawless throughout the more than four years in orbit. The battery has never been in undervoltage; the battery temperature has raised between 5 and 35 degrees Centigrade while in orbit. The maximum depth of discharge experienced in orbit is about 65 percent of the rated 6 ampere hour capacity.

dh16

The end of charge voltage, following a recent discharge, was the same as that of the first cycle experienced in orbit. The telemetered information about the battery consisted of battery temperature and bus voltage.

The next radio astronomy explorer mission will provide for telemetering battery current information. And the depth of discharge will be increased from 20 to 30 percent of rated capacity.

Next slide, please.

(Slide 157.)

Three manufacturers of nickel-cadmium spacecraft cells have made very satisfactory cadmium-cadmium Coulometers for the space agency. A question that may be forthcoming is, how can one determine if the cadmium-cadmium Coulometer is made properly? It does not store energy in any form; it is not chargeable like the nickel-cadmium cells. The quality can be determined by placing two parallel silicon power diodes in opposite directions across the terminals of the cells and then passing a current at a convenient rate, such as a C rate, through the cells alternately, while recording the ampere hours between voltage peaks.

Next, plot the ampere-hour values against the half cycle number. And if the device is a good one, it will yield a plateau in 15 to 20, 25 half cycles. And that's represented by the top curve in this slide.

Although the Coulometer is generally longer-lived than its nickel-cadmium counterpart, it will fail in time, and the mode of that failure is the same as the nickel-cadmium cell associated with it. NASA tests have been made and failure analyses been conducted, that reveal the presence of cadmium hydroxide throughout the separator material, causing shorting and failed cells. The cadmium hydroxide forms during oxidation of the negative electrode, the cadmium having migrated to the separator during negative reduction.

(Slide 158.)

RAE type cells were tested with Coulometer control while monitoring internal cell pressures at temperatures in the range of minus 20 to 50 degrees Centigrade. The zero test has been picked for us to look at because it is the lowest extreme experienced in orbit.

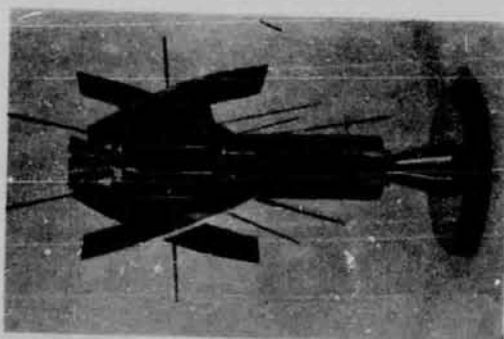


FIGURE 154



FIGURE 155

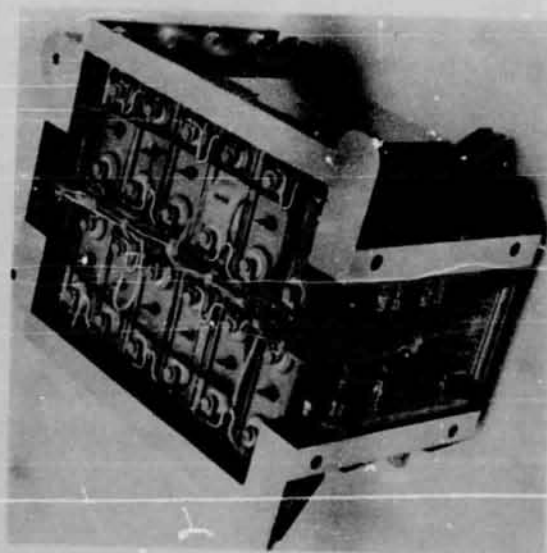


FIGURE 156

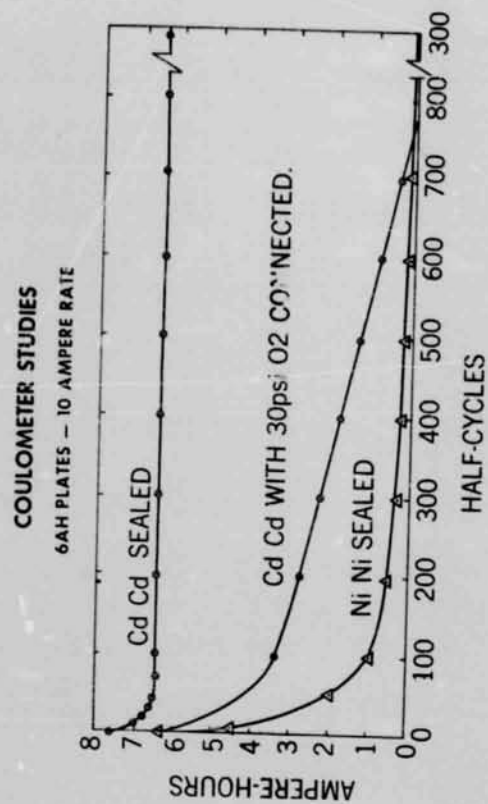


FIGURE 157

dh17

The internal pressures were monitored on two cells and varied 3 PSI, pounds per square inch, over the entire cycle. The temperature rise was recorded to 2 degrees Centigrade maximum. The specific pressures noted may best be described as having been between one and two thirds of one atmosphere.

Next, the battery was charged continuously at C/30 rate for 11 days at minus 10 degrees Centigrade, and the pressure was noted to stabilize at 20 pounds per square inch absolute. And the temperature rise stabilized at 2 degrees Centigrade.

First viewgraph, please.

(Slide 159.)

The flight battery was made up of vintage 1966 cells, which were two years old at the time of launch in 1968. The cells were stored in the shorted condition. The acceptance test included an electrolyte leak test, using phenolphthalein. An overcharge voltage test at the C/10 and C/5 rates at room temperature. A test for internal shorting tendencies, and a capacitor check.

The results shown here are those for the battery that is now in orbit in the radio astronomy explorer A. The overcharge voltages were essentially all at 1.45 volts. The capacities were remarkably uniform. The voltage recovery, following shorting, and the 24 hour open circuit stand was quite good; all well over the required 1.15 volts minimum.

These results are the best obtained from cells of this type and size.

Next viewgraph, please.

(Slide 160.)

The flight battery was fingerprinted by operating it at temperatures and charge and discharge rates that it is expected to experience in orbit. This information, to provide a base for interpretation of the telemetered information, the minus 10 degrees Centigrade test, taken during the 125th discharge, and the 126th charge cycle is shown here as an example of those tests.

The null voltage of the Colometer during discharge and charge periods, and the rate of rise to the end of charge

dh18

charge signal voltage, of one half to one volt, is readily apparent in this plot. Each of the eleven cell voltages are plotted, and they fall one on top of the other.

1.25 ampere hours was removed during discharge, and 1.57 ampere hours was returned during charging. The cell voltage at end of charge was 1.49, dropping to 1.46 on trickle.

Next viewgraph, please.

(Slide 161.)

The last complete discharge of the flight battery was conducted at the C/4 rate. The battery delivered 5.74 ampere hours to the under voltage condition of 12 volts. The first cell to be discharged yielded 6.45 ampere hours, and the last one down yielded 6.86 ampere hours.

The RAE cycle during the greatest dark experience, was to require not more than 1.2 ampere hours. This illustration here was the 174th discharge in the fingerprint testing of these cells at Goddard Space Flight Center. The test was conducted in a temperature chamber with the environment at 40 degrees Centigrade.

Cells were shorted when the voltage dropped to less than one half volt, in order to prevent reversal.

Last viewgraph, please.

(Slide 162.)

Four 5-cell test samples from the radio astronomy explorer A lot of nickel-cadmium cells were made and placed in NASA's space battery evaluation program at NAD/Crane to determine life capabilities of the cell at 25 percent depth of discharge and temperatures of minus 20, 0, 25 and 40 degrees Centigrade.

The charge and discharge rates were C/2 in all cases. The results here suggest the proposition that life expectancy varies inversely with increasing temperatures. The number of cycles obtained at minus 20 degrees Centigrade was approximately three times that of 40 degrees Centigrade. And twice that at zero degrees Centigrade.

That's all, Floyd. Thank you.

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR.

REPORT GILTON TYPE VO 6 REPORT'S NUMBER GAH DATE AND JUNE 1966

CELL #/N	PHOTO PAPER LARK TEST	DATE	TYPE	CLAMP	VOLTAZ	CAPACITY	WOLTAZ	RESISTANCE
209	OK 7-25-66		C/S	1.444	1.444	7.66	1.187	
214	OK 7-28-66		C/S	1.444	1.455	7.67	1.190	
225				1.446	1.459	7.60	1.202	
226				1.440	1.450	7.65	1.205	
228				1.446	1.451	7.64	1.194	
236	Y			1.444	1.452	7.66	1.191	
260	OK 7-4-66			1.450	1.459	7.63	1.206	
262				1.449	1.458	7.61	1.217	
265				1.449	1.449	7.62	1.208	
266				1.449	1.452	7.69	1.201	
274	Y			1.450	1.455	7.62	1.214	
157							DOUBLE WRAP	PENLOW

FIGURE 159

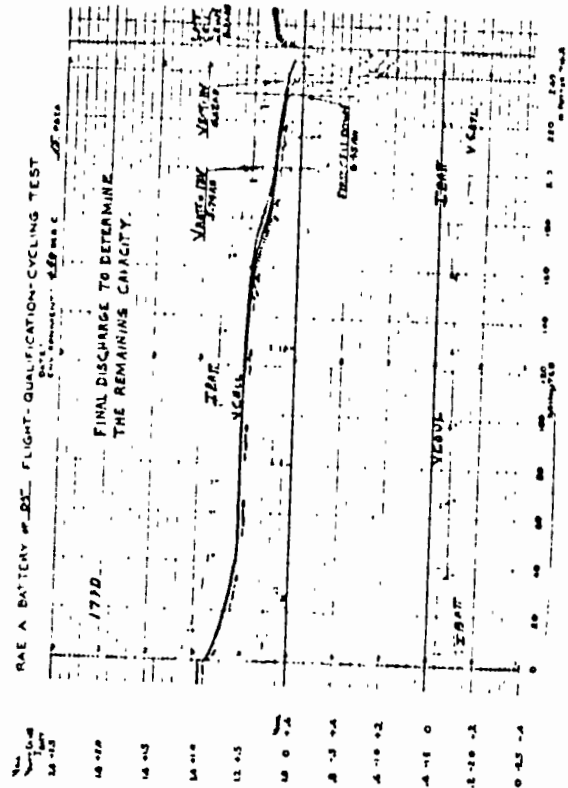


FIGURE 161

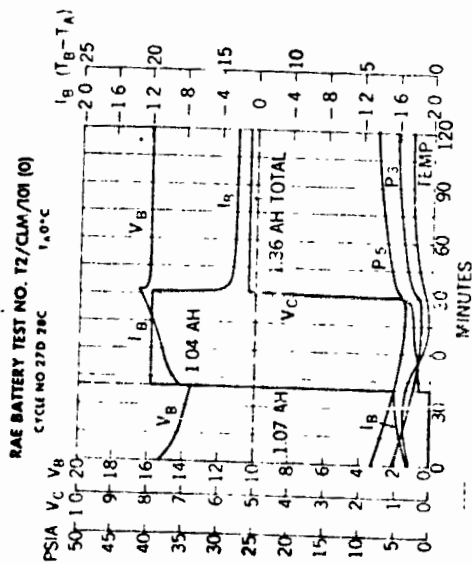


FIGURE 158

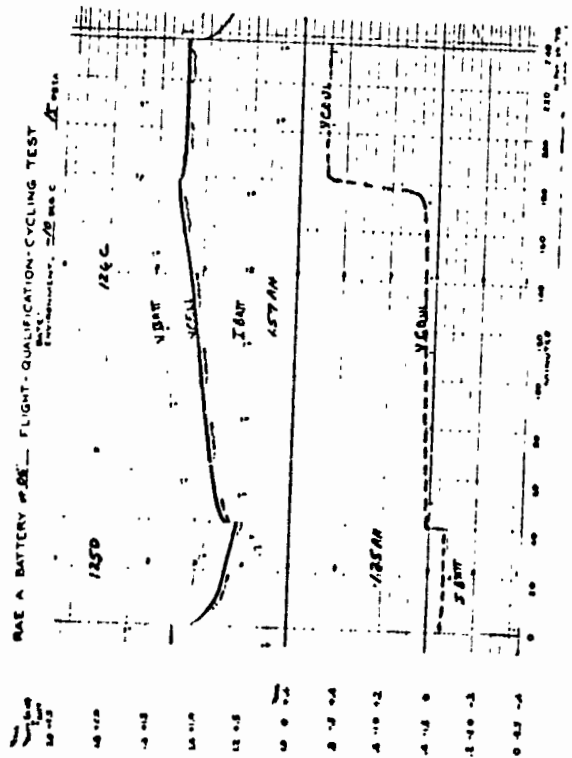


FIGURE 160

**RADIO ASTRONOMY EXPLORER SATELLITE BATTERY
LIFE TESTS AT CRANE, INDIANA IN NASA'S SPACE
BATTERY EVALUATION PROGRAM -**

TEST SAMPLES CONSIST OF FIVE NICD CELLS & ONE CDCD CELL

Pack No.	Pack Temp C°	% DOD	Chg. Rate	Disch. Rate	No. Pos. Completed
041B	-20	25	C/2	C/2	23067
066B	0	25	C/2	C/2	13396
018C	25	25	C/2	C/2	9633
029B	40	25	C/2	C/2	7941

FIGURE 162

Dh 19

FORD: Okay. Any questions?

SCOTT: A while ago, I had occasion to review the information available in the Crane test reports on testing of Coulometer cells, and I found it horrible. You know, it looked like 80 percent gross failures, and a big mess. Would you like to comment on that?

STROUP: Sure would, Will. Those were very early samples that were made by some manufacturers, and it'd be just as well not to mention the manufacturers, even, that we were dealing with at that time. Those Coulometers we were using out there at that time were not formed correctly. That has been corrected.

SCOTT: Is there any more recent vintage- type data, test data available on Coulometer cells?

STROUP: By Crane, as far as -- I don't believe they have any tests going on out there with using Coulometers. You see, we know what the problem was on those particular cells. It was strictly of not forming to the hydrogen plateau in each direction. And we even found, to our utter amazement and horror, that in one case, they were backfilling with oxygen before they closed the Coulometer cell, the cadmium-cadmium Coulometer.

And as you know, one of those electrodes is reduced to a pretty pure state of cadmium which has a close relationship activation as far as oxygen is concerned, and then in this particular case, they were semi-dry cells, too. They weren't flooding the cells.

So today, you noticed one of the things I said in here is, the Coulometers should be flooded. And that was another problem. Flooding, even if it backfilled with oxygen, may not be too bad, but the big problem was they were not forming the cells to the hydrogen plateau, and you have to get up to 1.65 volts and hold it there for a while.

STEINHAEUER: Jean, did you -- did I understand you to say that you specifically identified cadmium hydroxide as the migrating species.

STROUP: I believe what I said was the Crane had. I'm not sure. I didn't personally do the analysis.

FORD: Other questions, comments?

Okay, at this time, I'd like to do something that's

dh20

a little bit unusual, but we'd like to use your expertise to help us improve our own programs, and in helping us improve our programs, we hope we improve the information that we get to you.

Now Crane for several years has been running an acceptance test. I'm sure practically everyone here has these little reports stashed away somewhere. Whether you use them or not is another question. We are currently reviewing the Crane acceptance test, and are making revisions to it. And we're going to give you an opportunity to look at what we're proposing, we meaning Goddard and Crane, as a joint effort to come up with a new acceptance test plan on cells. We'd like your comment, your critique, and tell us just what you think about it.

At this time, I'd like for Don to come up and present his viewgraph.

MAINS: As Floyd mentioned, most of you may have already seen copies of our acceptance tests, but in the event you haven't, I thought I'd very briefly summarize what we do .

(Slide 163.)

As soon as the cells are received, we log them in. Their measurements been taken and recorded, we then leak check them, and this is done first with a phenolphthalein indicator, then we clean the cells. If they have shown any indications of leakage, they're releak checked, and cleaned again. We then run three capacity cycles, as noted on the viewgraph, followed then with an internal short test of a discharge, a half-ohm resistor placed across the cell for 16 hours, then the cell placed on open circuit and the 24 hour open circuit voltage recorded.

We then follow this with another leak test which consists of a high vacuum state for 24 hours, and then a phenolphthalein leak check, and the cells then are cleaned. They're then placed on an overcharge test, which consists of a charge at C/10 for 16 hours, followed then with a C/20 for 16 hours and a C/10 for 16 hours again. Each rate, we limit the voltage to one and a half volts per cell. If the cell reaches that voltage, it is discontinued on this part of the test.

We then follow this with an internal resistance check, using the Hewlitt-Packard milliohmmeter, which gives

dh21

us very consistent internal resistance measurements. And then we discharge the cells down to 0 volts, short the terminals, then repeat the high vacuum leak test where the cells are then either placed on storage or into a program, depending on what the next step in the program is.

The next viewgraph shows the new approach that we are now looking at. We're still planning on logging them in, measuring, and weighing them, so that we have some base information. The leak test will then follow, by using the high vacuum phenolphthalein indicator, and cleaning of the cells.

We'll then follow this with the three capacity cycles as before, but instead of, or during the third charge test, we'll run the internal resistance check with the milliohmmeter. This will then be followed by the internal resistance tests as before.

The next slide.

(Slide 164.)

Following this, we'll run a charge efficiency test, consisting of a charge at C/40 for 20 hours, and then a 24 hour stand, then discharge at C/2 to .5 volts. And then a comparison will be made of the capacity recovered as to that put in.

We'll follow this test with an overcharge test, consisting of a C/20 charge for 60 hours, watching the voltage and pressure, and then a discharge at C/2 to .5 volts. This, then will be followed by another C/10 charge for 24 hours. The previous test, I should have mentioned, would be at 0 degrees Centigrade. This one, then, will be run at 35 degrees C. And then discharged at the C/2 rate to .5 volts.

We will then follow this with another leak check. This time, simply spraying with phenolphthalein and cleaning the cells.

At this time, I'd like to open the floor up for discussion or comments, recommendations that anyone might have.

WERTHEIM: Wertheim, Grumman. Could I clarify a couple of points here, Don. I noticed that in your original conditioning, you charged to 1.55 per cell as the limit, and whereas in your overcharge test, you only go to 1.5.

ACCEPTANCE TEST OUTLINE
OF
NICKEL-CADMIUM SECONDARY SPACECRAFT CELLS
QUALITY EVALUATION & ENGINEERING LABORATORY
NAVAL AVIATION DEPOT
CRANF, INDIANA

D. E. MATIS

I. MEASUREMENTS

- A. Height
- B. Length.
- C. Width.
- D. Weight.

II. LEAK TEST

- A. Phenolphthalein indication.
- B. Clean cells.

III. CAPACITY TESTS--3 CYCLES

- A. Charge (c/10) for 16 hrs--1.550 V/C limit.
- B. Open circuit stand (0.C.V.)--1 hr.
- C. Discharge (c/2) to 1.000 V/C.
- D. 0.C.V.--1 hr.

IV. INTERNAL SHORT TEST

- A. Resistor (0.5 ohm) across cell--16 hrs.
- B. 0.C.V.--24 hrs (1.150 V/C recovery).

V. LEAK TEST

- A. High vacuum--24 hrs.
- B. Phenolphthalein indication.
- C. Clean cells.

FIGURE 163

VI. OVERCHARGE TEST ($20^{\circ} \pm 3^{\circ}$ C)

- A. Charge (c/10, c/20, c/10) for 16 hrs at each rate--1.500 V/C limit.

VII. INTERNAL CELL RESISTANCE TEST

- A. Measure internal cell and auxiliary electrode resistance with HIP milliohmmeter, Model 4325A.

VIII. LEAK TEST

- A. Discharge (c/2) to 0.000 V/C.
- B. Short cell terminals.
- C. High vacuum--24 hrs.
- D. Phenolphthalein indication.
- E. Clean cells.

FIGURE 164

dh22

What was the reason for that particular change?

MAINS: Well basically on the overcharge test, you have a lot of heating in that, and we were wanting to be sure we didn't go into thermal runaway. So that normally the cells are already up to their maximum voltage. And if we exceed the 1.50, we tend to go into thermal runaway, which we had done on a few occasions early in the program. So that's the reason we lowered that particular limit.

WERTHEIM: What, exactly, did you mean by the high voltage -- high vacuum test, excuse me.

MAINS: We placed the cells in a high vacuum chamber. It's about -- I believe it's 10^{-6} for 24 hours. The cells are placed in there in an attempt to pull any gas or KOH out of the cell if there is a very small leak. And we found that previously, we'd been running this at room ambient pressures, and we weren't getting any leaks or we were trying, and the original test was a bubble test, where you would place them in a container of water, and pull a vacuum on a complete container, looking for bubbles.

Both methods didn't net us any leakers. So we felt that by going to the higher vacuum, we might find some. The manufacturers are getting better and better, so we're still finding few leaks.

WERTHEIM: Can I just get in one more, Harvey? In connection with that, wouldn't you have a more meaningful test there if you were fully charged?

MAINS: Probably, because of the gas pressure inside. This was something we thought about, but because of the procedure, we had started when we were placing the cells in the water bath, they were always in the discharged state, and we continued that practice when we went into the high vacuum tank.

VOICE: I would suggest it.

SEIGER: What's the philosophy, and what's the criteria in the charge efficiency test at the C/40?

FORD: That's my test. We have, in the last six months -- we stumbled on this, believe it or not, for reasons that I don't want to go into. We found that this particular test condition at 20 degrees C., a C/40 charge, for 20 hours, so we put in half the rated capacity at C/40 rate.

dh23

And the CO₂ discharge; incidentally, I don't think there's an open circuit stand there that we have to. Our test immediately follows it with a CO₂ discharge. We're looking for the deliverable capacity out, versus a percent of what we took in, or put in.

We find ranges from 50 percent to a little better than 70 percent. Now, obviously, for certain applications, you may not be concerned about this. For synchronous applications, where you're charging at low rate, a lot of the times you are concerned about this type of charge efficiency. Because you're running at a lower state of charge; you're not always in on the charge.

SEIGER: I'd like to comment that there has been some published information showing that the charge efficiency is lower at lower current densities. And because it is a lower current density, the result might be dependent on cell design.

FORD: Okay.

WARINER: Warinerof Hughes. Do you have any other provision for a burn-in, or any cycling other than your capacity test?

FORD: No, there is no cycling in this program. And that may be a deficiency in the test. I don't defend that. These cells that Crane receives, it subjects to an acceptance test, whatever it may be, or it's destined for a cycling program. Some type of flight program, by the very fact that they're there.

I don't know if I answered the question or not.

WARINER: No, we've had experience thinking we'd find something after, oh, 15 days of cycling, or thinking that we get a good check on possible leak tests, things of that sort. Burn-in type of thing.

FORD: That's a very valid point.

MAURER: I have a comment on the efficiency test. We have found that if you take a cell completely discharged and charge it for let's say, return 10 percent of the charge, and try to discharge it, you may or may not get anything out. We've seen some cases where there was no capacity at all under those circumstances, and it seems to be related to this diffusion-controlled process that I mentioned earlier on the

dh24

positive electrode. It's also a diffusion controlled process on charge, and you simply don't have enough charge back in after you've shorted the cell overnight to provide any non-diffusion control discharge.

So, you have this test immediately following the open circuit recovery voltage test, and in this position, it will have the lowest efficiency. If you did the test after a normal discharge to 1 volt or half a volt, I think you'd get higher efficiency.

FORD: That's a very good point. Thank you.

GASTON: Gaston, Grumman. You implied that you measured the pressure, but you didn't exactly state it. Did you measure the pressure of each cell, do you have a pressure measuring device?

FORD: The pressure is only measured, Steve, on those cells we ship out with gauges. Now, that varies from program to program. Some in flight programs, we may have no gauges. In development programs, we will typically have 60 percent or more of the cells with some type of pressure-negative device.

GASTON: Another comment. You didn't mention it, but I'm sure you'll restrain each cell separately. Do you have developed a uniform mechanical preload value, or is it just an end tightened --

MAINS: We tried using a torque wrench setting, and found that we could get really more consistent tightening by using just a finger tight on the restrainer plates, because the thread resistance was getting into the area of what we wanted the torque to. And we don't use a wrench or anything like this; just finger-tight on the restrainer plates, we found this to be very adequate.

STEINHAUER: What's the purpose of the C/10, 35 degrees C. overcharge test?

FORD: It's more or less, if you want to call it a charge efficiency test, it's to see just how much of the ampere hours you can store under that condition. Again, based on history, we know that when we charge at that condition, the discharge -- we should get X percent of what we pass through on the discharge.

STEINHAUER: What, are you going to do this to

dh25

nylon cells?

FORD: That will be included if we go with the plan we have, yes.

STEINHAUER: Where are the rates at which you're enhancing cadmium migration at that temperature?

FORD: You know, I'd like to hear a little elaboration on that one.

STEINHAUER: In studying some possible anomalies during launch sequences, we have found that you can increase cadmium migration by several times, like five times, getting up, you know, in temperatures slightly above 100 Fahrenheit, I would think that as you go up, and particularly in an over-charged condition, you're going to be having a problem.

FORD: Okay. It's strictly a trade-off between how much of the data is useful to you, and what damage you think you might be doing internally during the roughly 25 hour period, 20 hour period of the test.

WERTHEIM: Either one of the gentlemen. This isn't meant to be an acceptance test for cells as I understand it, right?

FORD: Yes.

WERTHEIM: On that basis, when you do your initial height, weight, and so forth, would you do a complete inspection? We have seen cells at times that had other mechanical, visually observable mechanical problems.

MAINS: Yes, this is something I went over rather quickly, but as the cells are brought in, their serial numbers are checked, the cosmetics of the cell is checked to make certain that there aren't any blemishes, cracks, crazes, the seals are visually inspected. The whole thing is looked over as the person also carries out the weight measures and records these. There's a checked remark section on the data sheet for them to note any anomalies that they have uncovered in this -- at this particular time.

STEINHAUER: First, to elaborate a little bit. Floyd, on my last comment, this high temperature test that we simulated was like an eight hour period, so yes, you can incur significant change to the cell within a short period.

dh26

Second, what type of phenolphthalein tests are you running, and do you consider these adequate. We've had some experiences recently that I think we need better leak checking methods.

MAINS: At the present time, we are spraying a phenolphthalein solution of 50 percent alcohol and 50 percent water on the cell terminals around the weld areas and so forth, looking for changes in coloration.

STEINHAUER: Yes, that solution itself can actually act as a diluant, and you have to watch, on a very small leak, subtle leak, for a flash of a pink color which will rapidly disappear, and in many cases, we have to perform this type of test under a microscope.

SCOTT: In general, I feel that a lot of things hang on the results of the test program going on there at Crane, and I would urge you not to prejudice or bias the -- or make any less valuable the results of all those years of testing by skimping on the acceptance tests.

Especially, this may bear on the question of what you want to do more burn in cycling, whether you want to hang onto them a little bit longer before you decided that are really indeed acceptable for putting on your test program. It looks a little bit brief to me, in view of things that have been said here, and other things in general.

You know, I believe, in my opinion that there have been a number of tests that the results have been somewhat invalidated by the fact that the original cells were of questionable acceptance or quality or something because of the brief nature of the acceptance tests in the past.

One other point before I get off of this. I believe it has been shown in some cases that the impedance test, the using alternating current, I presume that's what Hewlett-Packard instrument does. Is much more definitive if you do it with the cell completely discharged.

With respect to the fact that if you have a marginal amount of electrolyte in that cell, you'll get much larger variation in impedance when the cell is completely discharged than you will when it's charged. And I suggest you might at least do additional impedance tests for the cell discharged as well as charged.

FORD: Thank you.

dh27

HENNIGAN: I have a comment on Will's suggestion there. The separator test that we just run, we were making impedance measurements. I think Fisher had some of the data here the other day.

The first time I ever saw any significance to these impedance measurements, and there was a specialty at end of discharge, when we had analyzed the cells and they were drying out, and on some of these materials, you could almost -- without opening the cell, tell the material was drying out, because this was after the fact.

So, we get a little more interesting impedance measurement, and at this time I was thinking of incorporating it in the accelerator test while the cell is cycling.

STEINHAUER: I would like to plead for more attention to synchronous orbits. They have been somewhat less frequent than lower orbit testing, and we could certainly use data of that nature.

FORD: You mean more tests in the synchronous orbit regime?

STEINHAUER: Yes.

FORD: I'd like to make a general comment. We really, in essence, have two types of cells going to Crane at the present time. One is the cell that's supplied by the project is tested under project funds, whether it be AE, OSO, and it's tested for the regime that that satellite is predicted to operate at. Those tests are -- they're project-oriented.

The other type of test -- and there's another thing, these cells that go on, they're under project category, have already gone through the acceptance tests by the manufacturer and by the prime contractor, or both in some cases, they may have gone through a fairly rigorous screening test.

The other type of cells are those type of cells that are new to development. Take, for instance, Tefanated negatives. The question comes up: How do you come up with a standardized acceptance test, and then subject new development cells to this test regime and say they have to pass it? It's not really a fair shake when you do this, because you're really trying to get a cell, and to find out just how long it's going to last.

dh28

So, we have to make some qualifications where we subject particularly new types of cells to the acceptance test, and whatever it would be that we would come up with.

I've got two things I want to leave you with.

I'm going to take one minute each on two slides and this is an update on what I completed last year. I was asked particularly by an individual to do this that's still here, and last year, we discussed the burn-in and cycling, and gentleman here mentioned that, and we are still experiencing that. What I've shown here is three different lots of OAO cells that we have now tested.

(Slide 165.)

This is one lot, 32, 33, 34, 35, if you look over in the left hand corner, you see that there's another lot that we now on test, and the interesting thing is that we're seeing this same the same characteristics when we turn on the cells -- these cells are manufactured over -- by the linear ____.

This is the burn-in characteristics that we have been talking about. We feel like it's real and a way of life. Now this is for a specific set of conditions, and a specific regime. But this goes back to the point I made yesterday about the burn-in, maybe it's a redistribution of electrolyte, whatever. I can't help believe there's a tie between what was discussed yesterday and what we see in launch performance.

(Slide 166.)

This one, I couldn't let you go without seeing this, because this personifies our problem. Even with the specifications we have today, I'm showing you that in spite of everything we can do, we still don't get the same cells that we go out and buy two and three years apart.

What you see is a comparison of two different lots, subjected to approximately one year of cycling. The top curve is 50 cycles, and then you see the second curve that shows the onset of degradation and the discharge characteristics after one year. This is the second lot showing what it looked like on day one. This shows what those same cells looked like after about one year.

We don't know what caused this; we don't know what the difference is between the lots, but it's pretty obvious there's some differences. We're still looking at

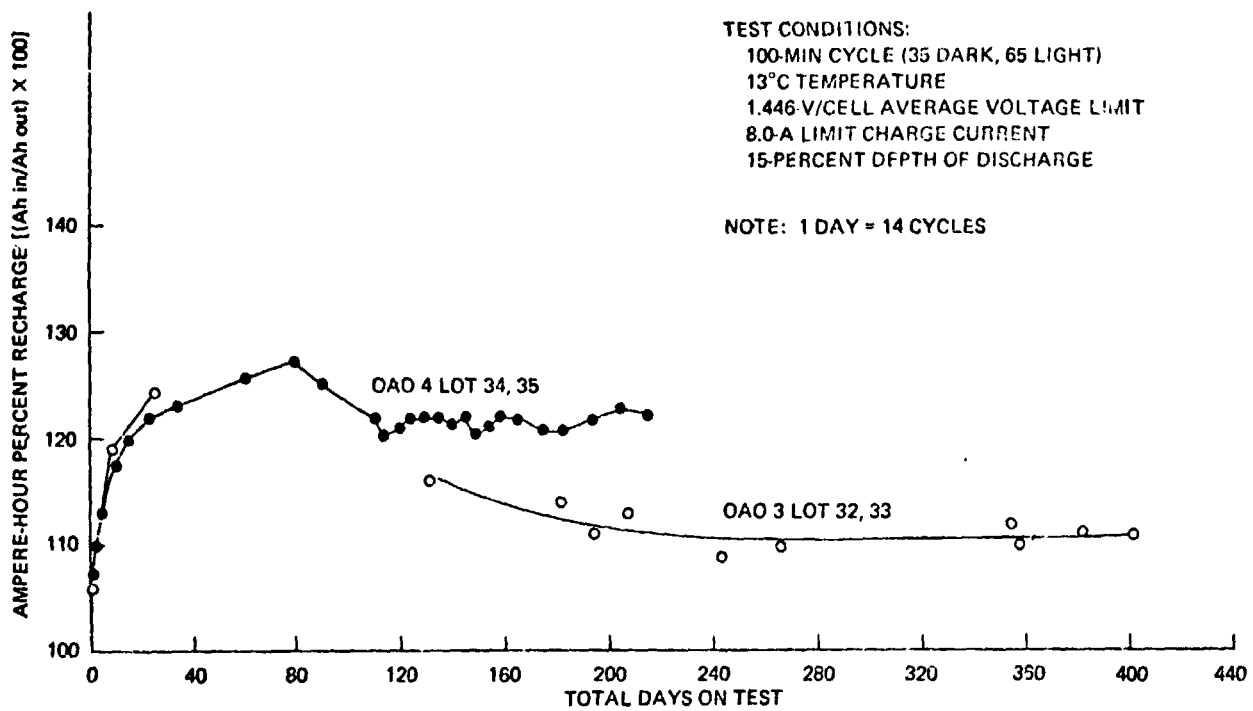


FIGURE 165

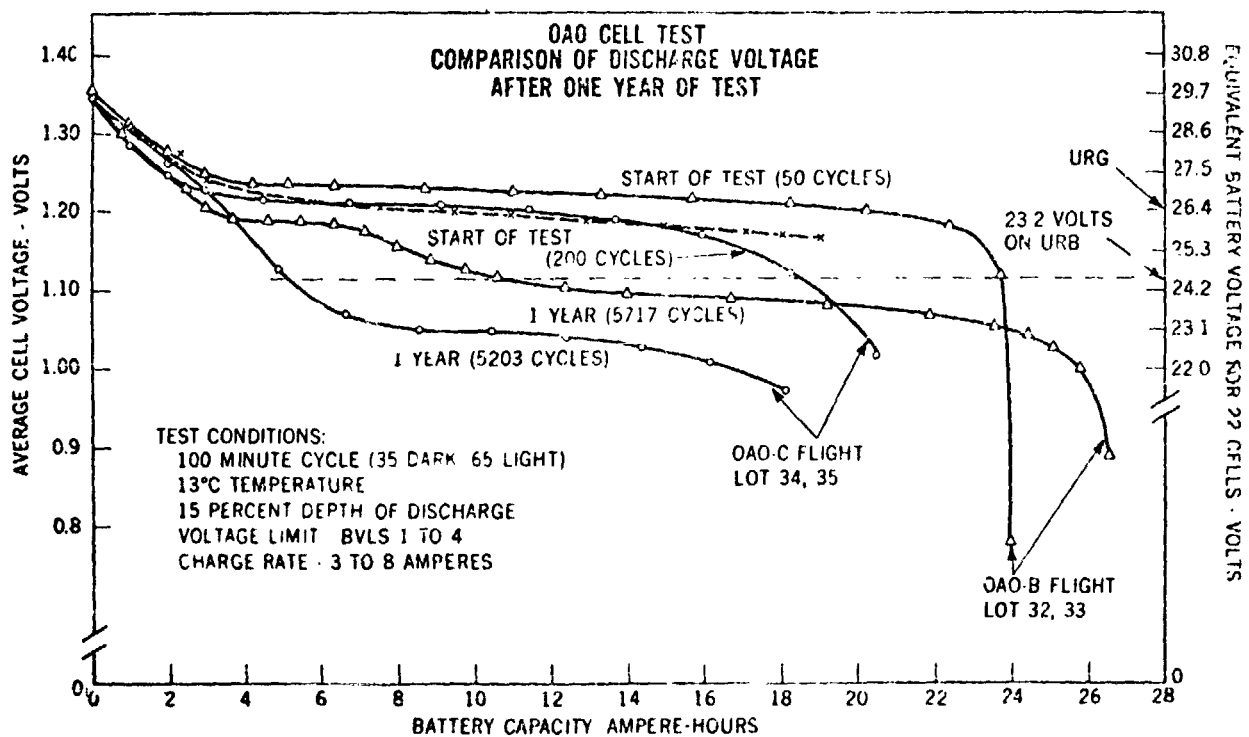


FIGURE 166

dh29

it, maybe by next year's workshop, I can have some further inputs.

GASTON: Since we're talking about testing, I just have one quick comment. For all cells which are tested with pressure gauges, we have modified a little switch inside the pressure gauge, which shuts off your charging system or discharging, whatever a cell is at, and prevents any blow-up because of high pressures.

I think we have a slide here; I don't know if we have time to show it. It might be of general interest.

FORD: If you'd like to put it in, be my guest.

GASTON: This is a standard compound gauge which we modified, and can be done relatively quickly and cheaply.

(No slide.)

FORD: Okay, Steve. Thank you.

Was there another question?

(Inaudible remark.)

HALPERT: If you care to put it in the minutes, Steve, you can send it to us, and it'll be all right.

GASTON: Apologize. The slide got wrecked; we don't have it.

HALPERT: Well, in summing up, in concluding the meeting, I first want to apologize to several people whom we had asked to speak, or offered to speak on certain issues, and we were not able to get around to them. We hope that in the next go around, we'll be able to work the program to an extent that everyone will get a chance, or those who have some important information will get a chance to speak, and be planned properly.

If you have some comments and criticisms, positive criticisms, that you'd like us to hear about, we'd be very happy to hear so we can plan better for next year.

I want to make sure we all get our photos and figures in. There's still quite a few missing, and I'm going to have to do a lot of calling, and it'll save a lot of time and energy if you send them in right away, please.

dh30

I want to thank all of you for participating. I think we had a pretty active meeting. As shown by this morning, this afternoon and yesterday, and I want to thank all of our foreign visitors who came from a long distance, and our west coast visitors to attend the meeting, and I look forward to seeing you all next year.

(Applause.)

I also want to thank our session chairman and all the Goddard people who helped out.

FORD: And what about a show of gratitude for this fine stenographer we have up here?

(Applause.)

(Whereupon, at 5 p.m., the workshop adjourned.)